KAITIAKITANGA MŌ TE KIEKIE –

SUSTAINABLE HARVEST OF

FREYCINETIA BANKSII

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ABSTRACT

For generations, the harvest of native flora and fauna by Māori was guided by tikanga. In the art of weaving, the sustainability of the culture was greatly dependant on the careful practice of harvest to ensure the maintenance of resources for future generations – also known as kaitiakitanga. One of the most important weaving materials was the kiekie (*Freycinetia banksii*). Under tikanga, the traditional method of harvest was to use a hand wrench. This method, it was argued, encouraged vigorous replenishment of the harvested stem, thus mediating human impacts on the resource. However, over the last decade it has arisen that a minority of harvesters may be adopting non-traditional techniques which involve the removal of the entire leaf head. Consequently, patches are slow to recover, and in some cases, the affected stems perish. Despite these observations, there is little in the way of quantitative data. As a result, Te Roopu Raranga Whatu o Aotearoa instigated this research to investigate harvesting practices and their impacts on kiekie.

Over 1.5 years, I tested whether traditional harvest was the most appropriate method by measuring how different harvesting techniques affected the recovery of harvested stems at two sites – one at Te Kotuku Whakaoka (Lake Brunner) on the west coast of the South Island, and the second in the Kaimai Ranges, west of Rotorua, in the North Island. Sixty stems at each site were treated with one of three different harvest regimes – a traditional hand wrench that removed approx. one-third of the stem tip biomass and was conducted over two different seasons ((1) spring and (2) autumn), and (3) a non-traditional harvest technique removing 100 % of the stem tip biomass with loppers. An additional investigation was conducted to evaluate the recovery of kiekie after goat browse. To simulate herbivory, 50 % of the total leaf area of the stem tip was removed from twenty of the sixty treatment stems. Results showed that the herbivory treatments significantly slowed new leaf production on the stems, when compared to controls.

Overall, costs of harvest were higher for the non-traditional method than the traditional techniques. Non-traditionally harvested stems had a poorer recovery, with 20 % dying, and only 27 % of the remaining stems regenerating with an average of 1.73 side shoots. In comparison, the two traditionally hand wrenched stems produced an average of 2.35 (Spring Wrench) and 2.55 (Autumn Wrench) side shoots. Findings also showed that traditionally hand wrenched stems are recovering back lost resources. One and a half years after harvest, the Spring Wrench shoots had recovered 70 % of the removed biomass (dry weight). Average leaf lengths of the three longest shoot leaves on all side shoots per wrench stem were at ~ 38 % of mature leaf size. One year after harvest Autumn Wrench shoots had recovered 2.7 % of the removed biomass (dry weight) and shoot leaves were at ~ 19 % of mature leaf size. Consequently, both are capable of photosynthate synthesis and supply. Measurements did indicate however, that recovery may be sped up in the Autumn Wrench stems which produced more new shoot leaves on all side shoots than the Spring Wrench stems one year after harvest (32.1 and 26.9 shoot leaves respectively); although these results apply to a short research period and could be enhanced by a longer-term study. The findings

validate the concerns of weavers regarding the negative impacts of non-traditional harvest on the sustainability of kiekie resources. Furthermore, there is support for tikanga regarding kiekie harvest. The regeneration of stocks shows that of all the harvest techniques investigated, the traditional modes of harvest are the most effective means of mediating the impacts of human harvest on kiekie.

Dedicated to my mum

Ann (Ani) Te Rongonui Ashford

1937 – 2007

Kaahore ngenge koe inaianei e Maa
Hine e hine

GLOSSARY of MĀORI TERMS

Aka(-kiekie)	Name given to the long aerial roots of climbing plants such as kiekie, kareao (supplejack) etc
Atua	Deity, commonly interpreted as 'god'
Hapū:	Commonly defined as 'sub-tribe'; to be pregnant
Hīnaki:	Eel nets/pots
Iwi:	Tribe or nation; bone
Kaitiaki-(tanga):	Guardian or caretaker; parentheses: act of guardianship; also **te hunga tiaki** – the responsibility of the group as guardians
Kaitiakitanga mō te kiekie:	Literally means 'Guardianship for the kiekie'; but in essence is about ensuring the long term sustainability of the resource
Kawa:	Protocols
Kete (Whakairo):	Finely woven bags of plant materials such as harakeke or kiekie. The term 'whakairo' relates to the patterns that may be woven into the bag's design
Mana Whenua:	The people of the immediate area with the right of protocol and kaitiakitanga over that area. This applies to those descendants of iwi / hapū who are affiliated with a particular locale, as opposed to others from another locale within the same region (see also Tangata Whenua).
Manga (-harakiekie):	[freshwater] Stream (of / with kiekie)
Mātauranga:	Knowledge systems related to Te Ao Māori
Maunga (-kiekie):	Mountain (of / with kiekie)
Rāhui:	Temporary prohibition enforced and managed by mana whenua.

Raranga:	Plaiting or weaving
Roopu:	Group or society
[Te] Roopu Raranga Whatu o Aotearoa:	National Weavers Guild of Aotearoa
Rohe:	Hapū / iwi territory
Tangata Whenua:	Commonly used to describe indigenous New Zealanders, 'people of the land'
Taonga:	Something of extreme value and importance. Often translated as a 'treasure' but it could be argued that is it more than this.
Tāwhara:	Name given to the bracts of the male kiekie inflorescence. Named after the guardian of kiekie – Tāwharanui
Teina:	Younger sibling
Te Kōtuku Whakaoka:	The traditional name of the West Coast (South Island) lake now known as Lake Brunner. Literally means 'the diving kōtuku (white heron)'.
Tikanga:	Custom or criterion; in the context of this research is defined as the guidelines and practices adopted to mediate harvest.
Tuakana:	Elder sibling
Tukutuku:	Weaving panels that adorn the inside walls of the wharenui.
Ureure / Tīori:	The names given to the female fruit of the kiekie.
Waka Manu:	A bird trap. Shaped like a waka (boat), tiny nooses (usually made of kiekie fibres) were placed above the waka, which was filled with water. Thirsty birds, unbeknownst to them, would place their heads through the noose as they took a drink.

Whakapapa:	Layers of kin-relationships; genealogy
Whakatipua:	"Growing time"; used by some North Island hapuu to describe a temporary prohibition on harvest in order to allow stocks to regenerate.
Whare:	A traditional abode; often attributed to any house-type building
Whariki:	Sleeping, floor or wall mats woven from plant materials such as harakeke (*Phormium tenax*), kiekie, and others.
Whatu:	Weaving with the muka (fibres) of harakeke

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This one is for my mum – sleep well mummy, until we meet again…

"Weaving is more than manual skills, more than producing a functional item, more than creating an item of beauty…Customs, traditions, history, music, oratory, legend and the needs of an iwi, hapū, whānau are all drawn together within an individual who becomes a weaver, who creates or weaves not for herself alone, but for the mana of the people."

- Taonga Maaori, Treasures of the New Zealand Maaori People, cited in Tamati-Quennell, 1993: 6.

Kiekie on a Totara host, Te Kotuku Whakaoka, South Island.
Photo: S. Scheele, November 2005

CHAPTER 1 - INTRODUCTION

Kin-relationships between humans and the plants and animals they share the natural world with are embedded within the ecology of many Pacific-based cultures (P.A; Cox & Elmqvist, 1993). The utilisation of natural resources by Polynesians formed a significant part of their expression as unique cultures, and aided in the translation of oratories and traditions through the generations (Weaver, 1997). Access to locally-sourced resources also placed the affiliated communities with economic advantages, particularly in trading for items or goods that were scarce or absent within their lands (Cooper & Cambie, 1991).These intimate interactions between humans and the natural world developed over a long time, involved trial and error, and culminated in the accumulation of a deep understanding of the ecology of the phenomenon in question (Berkes, *et al.,* 2000; Berkes, *et al.,* 1998; Moller, 1996). Intertwined into this dependence upon natural resources were strict guidelines and protocols *(*tikanga and kawa) that were adopted as a means of mediating the impacts of harvest (Kirikiri & Nugent, 1995; Papakura, 1986), ensuring the long-term viability of the resources for future generations (Kaitiakitanga) (Mihinui, 2002). Such a relationship existed between Māori and the New Zealand kiekie (*Freycinetia banksii* A .Cunn.).

Kiekie is a plant species highly valued by Māori, particularly for its use in weaving (Colenso, 1891; Evans & Ngarimu, 2005; Prendergrast, 1987; Riley, 2005; Ruhia Oketopa (interview) - Tamati-Quennell, 1993). In response to a call from Te Roopu Raranga Whatu o Aotearoa (The National Weavers' Guild), this scientific study was undertaken to investigate current methods of harvest and the potential effects on the long-term sustainability of kiekie resources. This chapter is a brief introduction to this native liane, and provides an overview of some of the literature relevant to this research. Other references particularly pertinent to chapters three and four are found in their introductory paragraphs.

1.1 About *Freycinetia banksii*

The genus *Freycinetia* is one of three within the old world tropical plant family known as Pandanaceae, or Pandans (Dawson, 1988; but also see Callmander, *et al.*, 2003). The oldest

fossil records of the Pandanaceae (known as the *Pandaniidites*) date back to 69 million years ago (mya), and possibly even further back to the Early Cretaceous (96 Mya). The later appearance of *Freycinetia* within the pollen record (around the beginning of the Late Cretaceaous) suggests that this species may have a more recent origin, although there is still much to be learnt about this (Callmander, *et al.,* 2003). Since the split of the great ancient land mass of Gondwanaland, the distribution of the genus, along with the two other genera - *Pandanus* and *Sararanga* - has become predominantly located within the tropical Pacific (Dahlgren & Clifford, 1982). Over 60 species of *Freycinetia* have been recorded within this region (Smith-Dodsworth, 1991) extending from Malaysia to Australia, Hawai'i to Samoa, and from the Norfolk Islands to Rapanui (Easter Island) (Glenn, 1959; Stone, 1973). The New Zealand species known locally as kiekie is somewhat of a phenomenon, being the only member of the genus and family to inhabit the temperate forests of New Zealand (its southern limit), and therefore, contradicting the typical tropical and subtropical habitats of the other members of this group.

Each of the three genera within the Pandanaceae family display distinct morphological differences (Stone, 1983). The most common genus, *Pandanus* (over 900 recorded species) is a self supporting tree with prop roots at the base of its trunk. The second tree genus, *Sararanga*, is rarer and the most understudied of the three genera with only two known species within the Indonesian/ Irian Jaya region of the Pacific. *Freycinetia* is the only climbing plant group, or liane in the family (Dahlgren, *et al.,* 1985).

Lianas (also known as vines) are found throughout temperate and tropical forests around the world (Gentry, 1991). They can be characterised by their thin stems (most with diameters around 4 - 5 cm) and expansive leaf crowns. Despite the growing international interest in the role that climbing plants could play in the architecture and productivity of their forest habitats (Alvira, *et al.,* 2004; Grauel & Putz, 2004; Hegarty, 1991; Schnitzer & Bongers, 2002; Schnitzer, *et al.,* 2004), they still remain one of the most understudied plant groups (Putz & Mooney, 1991). Even less is understood about the temperate species (Burns & Dawson, 2005). Not only does this research serve to build upon the current understanding of kiekie ecology, it is also one of the first that explores the utilisation of this liane by weavers.

1.2 Distribution

Preferentially a lowland growing plant, kiekie are predominantly associated with podocarp-broadleaf forest, growing to a maximum altitude of 1500m (Moore & Edgar, 1970). Even though it is more closely associated with the podocarps (tōtara - *Podocarpus totara*, kahikatea – *Dacrycarpus dacrydiodes*, rimu – *Dacrydium cupressinum*, kauri - *Agathis australis,* and matai - *Prumnopitys taxifolia*), kiekie appear to cope just as well under a tāwhai (*Nothofagus solandri* var. *solandri*) canopy (King & Sweetman, 2001).

The current national conservation ranking of kiekie is as abundant to very abundant, and dense clusters of kiekie extend down the length of the west coast of the South Island (Te Wai Pounamu) (Crawley & Brown, 1971), as far south as Milford Sound (Poole & Adam, 1994). With the distribution stretching across the Nelson-Marlborough region and onto the east coast of the South Island, the plant reaches its southern limit on that coast just south of Kaikoura (latitude 42^{o}), near the Clarence River (Lord, 1991).

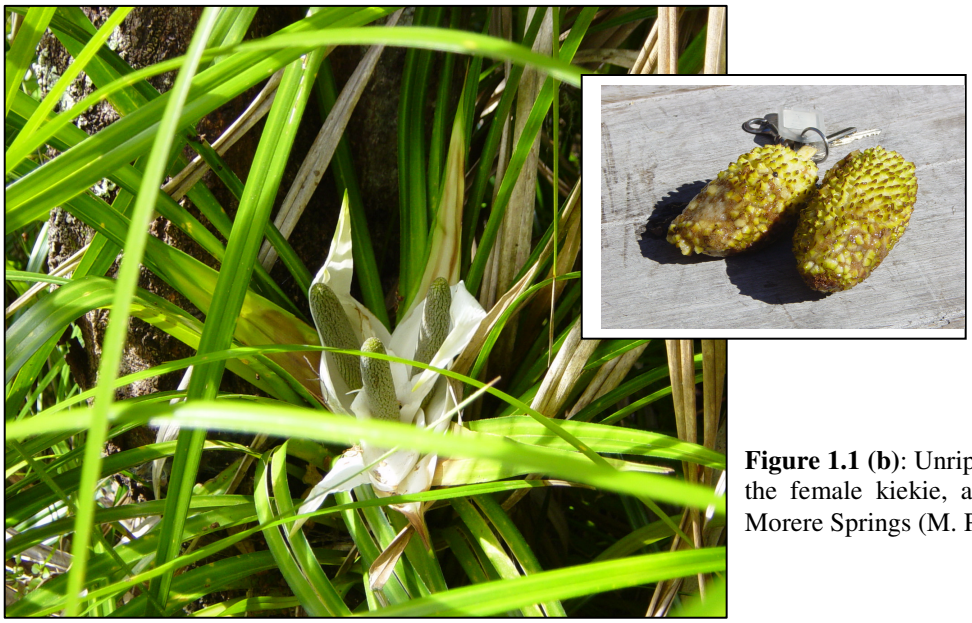
In the North Island, kiekie are found throughout the conservation estate (DoC, 2004), although it is argued by tangata whenua (indigenous New Zealanders; 'people of the land') that accessibility is declining (for some distribution information see Burns & Leathwick, 1996; Clarkson, 1983; Moorhouse, 1997). Historically, kiekie would have been found anywhere that podocarp-broadleaf forests existed within the mainland. Since human arrival, and certainly since European colonization, conversion of significant tracts of forest for agricultural land, and then urban expansion has substantially decreased the area of forest habitat for the plant (Atkinson & Cameron, 1993). Consequently, pockets of kiekie are being pushed higher toward the plant's altitudinal limit (1500m) making accessibility for harvest difficult (Ranui Ngarimu, *pers. comm.*). In some districts, vegetative surveys are highlighting an overall absence of these plants within the lowland forest remnants that they would have once been associated with (e.g. the Manawatu region, see Paneke Trust, 1990). Some of the other issues surrounding accessibility to kiekie resources will be outlined later; but also see chapter 2.

1.3 Reproductive strategies – sexual and vegetative reproduction

Kiekie is a dioecious (separate male and female) plant (Huynh & Sampson, 1992; Stone, 1973) flowering in 'significant amounts' on average every seven to ten years (Smith-Dodsworth, 1991: 96) (Figure 1.1 (a) – 1.1 (b)). In addition to being the only member of the Pandans to display climbing habits, *Freycinetia* is also the only genus to produce aggregated berries (roughly between 6-12 stigmas per berry in the kiekie) (Stone, 1973), as opposed to the nuts of *Sararanga*, and the pineapple-like drupes of *Pandanus* (Cox, 2005) (see Inset, Figure 1.1(b)). The sugary tāwhara (bracts) of the male kiekie; and the ripe banana-coloured ureure (fruit) of the female were, and still are, a delicacy for Māori, and earned it the attention of early ethnographers for being the only native plant that '*provided food twice a year*' (Colenso, 1880: p. 32).

Very little is understood about its pollination and seed dispersal. Past research into the pekapeka (native lesser short-tailed bat, *Mystacina tuberculata*) colony in the Omahuta Forest, Northland, has produced the most comprehensive data with regard to the feeding upon, and pollination of kiekie by pekapeka (Daniel, 1976). Guano and fur analyses showed high levels of kiekie seeds and remnants of the fruits of the female plant, indicating that pekapeka may also have an important role as a seed disperser (ibid). Investigations into *Freycinetia*-pollinator assemblages within the tropics further support the suggestion that an important relationship has evolved between the plant and this group of animals (see Lloyd, 1985).

Figure 1.1 (a): The tāwhara (bracts) of the male kiekie; a summer delicacy, Kaimai Ranges



Inset: The ripe ureure (M. Palmer, 2004)

Figure 1.1 (b): Unripe ureure (fruit) of the female kiekie, a winter delicacy, Morere Springs (M. Palmer, 2004)

Despite the pollinator relationships apparent between kiekie and pekapeka, perhaps the most fascinating characteristic of kiekie is that it is not solely dependant upon sexual reproduction. As Janice Lord (1991) highlighted in her research, kiekie have capably maintained stocks even in the absence of its primary pollinator, as have other *Freycinetia;* e.g. 'ie'ie, *F. arborea* in Hawai'i (Cox, 1983). However, the argument of Paul Cox and Thomas Elmqvist (2000) was that the long term survival of 'ie'ie was only assured due to its lack of pollinator specialisation. Studies of other *Freycinetia* from the Pacific suggest that this genus may also have the ability to switch to a bisexual reproductive system in the absence of suitable pollinators (Cox, 1982; Huynh & Cox, 1992; Poppendieck, 1987). Due to the infrequency of major flowering events in kiekie and the lack of evidence to both suggest bisexualism, and that successful pollination is still occurring in the absence of pekapeka (although see Lord, 1991), it is more likely that this plant is primarily a vegetative reproducer, hence my interest in this particular system for this study.

Vegetative reproduction or 'sprouting' (Bond & Midgley, 2001) is likely to be an evolved strategy in climbing plants to mediate the damage associated with the environments in which they exist (Fisher & Ewers, 1991). Due to the absence of secondary thickening in their own thin stems, this group of plants are heavily reliant upon mature tree hosts to aid in their growth

towards the canopy and the abundance of light there (Putz & Mooney, 1991). As a result they are exposed to increased incidences of host tree fall (Putz, 1983) amongst other environmental risks such as wind throw.

An additional explanation for the sprouting behaviour may be poor recruitment (Bond & Midgley, 2001). Kiekie seeds are amongst the smallest of the native flora ($\geq$ 1 mm) (Burrows, 1996), but do not appear to be wind-dispersed, and seed banks are transient (Moles, *et al.,* 2000. These characteristics, coupled with prolonged periods between flowering (see earlier) may hinder successful recruitment in the species, although to what degree, it is not understood. If this is the case, sprouting confers an added advantage to plants, allowing them to persist within their environments.

Compared to sexual reproduction, vegetative reproduction has numerous competitive advantages. Examples in the literature include the benefit of enhancing growth rates to rapidly colonize canopy gaps (Gentry, 1991; Mooney & Gartner, 1991), and to augment the total leaf area, enabling plants to shade out competitors (Castellanos, 1991). Enhanced leaf development and increased total leaf area subsequently boost the exploitation of light resources and increase photosynthetic production. Accumulation and carbon storage ability within the leaf crown is also increased, hence improving plant fitness (Strauss & Agrawal, 1999). The effect of these facets of kiekie regeneration following human harvest will be investigated more closely within chapters three and four.

1.4 The cultural importance of kiekie – background to the research

The strong ties that many indigenous peoples feel with the natural world reflects to their understanding of life's beginnings (Cox & Elmqvist, 1993; Kepler, 1998; Moon, 2005). In New Zealand, the generally accepted interpretation is that whakapapa (layers of kin-relationships) describes a genealogy of descendants from Papatuanuku (earth mother), and Ranginui-e-tu-nei (sky father). It depicts the trees, birds and insects as the children of Tāne-Mahuta (Guardian or Atua of the forests) (Orbell, 2004 (rev)), and the youngest descendants in this lineage as humans; hence we are viewed as being a part of nature (Best, 1907). To many hapū and iwi, the

position of humans as the younger (teina) necessitates a responsibility to ensure that the elder (tuakana) natural resources are cared and protected for. This concept of intergenerational responsibility is described as te hunga tiaki (the responsibility of the group) or kaitiakitanga (Mihinui, 2002). (There are regional variations of environmental whakapapa, so for a more in depth discussion about these traditions please refer to Roberts, *et al.,* 1995).

Unlike the past romantic notions of some, these responsibilities do not imply a "lock-up and leave alone" protection (Gillespie, 1998). Due to the heavy dependence upon natural resources for all aspects of life in traditional Māori society, resources were utilised in as respectful a manner as possible (Wright, *et al.,* 1995; also see Kitson, 2002; Lyver, 2000; Stevens, 2003). This is described by some as cultural ecological resilience, or the balancing of natural resource use with their protection (Adger, 2000). Failure to ensure the continuance of these resources not only meant the extinction of those materials, but also the disintegration of the culture associated with its use. Therefore, harvest was dictated by protocols and guidelines (tikanga) that were conceived over generations of observation and practice, and were aimed at mediating human impacts upon the natural environment (Papakura, 1986).

Second to the harakeke (*Phormium tenax*), kiekie is the most important plant material used in weaving. The strong and durable fibres within the leaves are readily incorporated into the construction of fine whariki (mats) (Best, 1907; Colenso, 1868), kete (bags), rain coats (Best, 1898), waka manu (bird traps) (Burtenshaw, *et al*., 1999) and tukutuku panels (Puketapu-Hetet, 1999). The long 'feeder' roots (aka) also proved useful as bindings in whare (building) construction (Burtenshaw, *et al.*, 1999), and in the construction of hīnaki (eel traps).

In order to mediate the impacts of harvest of this important weaving plant, traditional management involved careful harvesting techniques coupled with management tools such as rāhui or whakatipua, and possibly rotational harvesting. Harvest of kiekie was done by hand wrenching, that is snapping the stem tip leaves by hand, and removing approx. one-third of the leafy biomass (Anon., 1988). For most roopu, harvest occurred during autumn (Ranui Ngarimu, *pers. comm.*), although for others the warmer period of late spring to early summer was preferred (Mihinui, 2002). Under tikanga, the hand wrench and the season of harvest was deemed to be the most appropriate way to reconcile the impact of human harvest. Not only

would stems regenerate within a time frame of about 4 years, but it was also argued that it would replenish the patch as a whole. Traditional harvest was then a means of encouraging vigorous vegetative regeneration of the harvested stem in the form of two or more new side shoots (Ranui Ngarimu, *pers. comm.*), a growth response that is supported by past studies into other vine species (see section 1.3).

Kiekie resources were also very carefully monitored and managed. When appropriate, decisions made by the kaitiaki of the resource included traditional management tools such as rāhui or whakatipua, which were adopted as a temporary prohibition to support regeneration. Because of their value as a food item, harvest seasons may have also been rotated with flowering periods although information on this is sketchy. Overall, these processes remained intact for many generations.

The period following colonisation, however, saw the weakening of a considerable ecological knowledge base of many hapū and iwi (Irwin & Ruru, 2002). Although investigations have shown that many social groups maintained traditional practices relating to resource harvesting, a minority may have adopted *ad hoc* techniques which inadvertently counter the ethos of sustainability. This is especially applicable to harvest of kiekie. Whilst most groups use the traditional method of hand wrenching, there is evidence of harvest involving the removal of the entire leaf crown of each harvested stem, usually with the aid of implements such as loppers or machetes. Anecdotal evidence indicates that the non-traditional method is detrimental to regeneration, either through retarding recovery or by killing stems. However, there is little in the way of quantitative data to support the understanding that traditional methods replenish resources, and that non-traditional methods can diminish them.

The acknowledgement that some harvesters are adopting unsustainable methods is further compounded by the problems of accessing quality kiekie resources. There are several reasons for these difficulties. Firstly, as outlined earlier, the distribution of accessible patches has declined markedly, particularly in areas of the North Island. Cultural cartography (mapping) in the form of (1) traditional regional oratories, (2) local hapū/iwi names for landscape features, and (3) past locations of importance (e.g. pa sites and other wāhi tapū) provide some assistance in locating past kiekie distribution. This is particularly relevant to those areas where the kiekie

has declined, or disappeared. An infamous example is the prominent volcanic feature of Auckland known as 'One Tree Hill'. This site was possibly once inundated with the plant, as suggested by its traditional name of "Maunga**kiekie**" – the mountain with kiekie (Cornwall Parks Board, c.2005). Areas along the Awakino River, Taranaki, also possess location descriptors, such as the "Mangahara**kiekie** stream" (Skinner, 1858), which suggest that this locale may have been an important area for kiekie harvest by the local peoples.

The areas where an abundant supply of kiekie remains are held either within, or on the fringes of the conservation estate. As a result, these resources are no longer managed under the traditional authority of mana whenua (the local hapū). And because resources are disappearing within some rohe, conflicts over limited kiekie supplies have started to arise as a result of the increase in demand.

Through various legislative changes starting with the New Zealand Forests Act (1874), and leading to the Conservation Act (1987), the management of the natural estates has been devolved to national government authorities such as the Department of Conservation (DoC) (Galbreath, 2002). Legislative changes to the authority over natural resources have not only imposed a different set of laws upon traditional harvesters, but have also compromised the role played by mana whenua as the guardians (kaitiaki) of the resources within their traditional lands (Coombes, 2007; Paneke Trust, 1990). Since the passing of the Reserves Act (1977) and its replacement, the Conservation Act (1987), kiekie harvesters have been bound to a process which involves making an application for a harvest permit from DoC.

In theory, the permit system should alleviate pressures on the amount of kiekie extracted from an area, particularly when being harvested by outside roopu. Yet traditional understanding of moving into the rohe of another hapū or iwi would have required that checks were first made with mana whenua. This was not only as a sign of respect for their role as the local [traditional] authority, but also because their knowledge of the resource may be more attuned to the changes within the stocks. However, because DoC manages the conservation estate for the 'public good' the assumption made by some outside roopu is that as tangata whenua they all have equal rights to the resource (Coombes, 2007). Under the current system there is no legislative requirement to meet with mana whenua, and there is some evidence to suggest that extractions endorsed under

the permit system can be overestimated if the traditional rāhui of four years between harvests is not understood (Coombes, 2007). Coupled with an absence of monitoring of the harvest methods used - especially if non-traditional methods are adopted - there is a genuine concern that kiekie stocks are being severely compromised.

1.5 Research Questions and Objectives

This research project does not delve any further into the political issues surrounding extraction rates, nor does it try to provide answers regarding who should manage what and why (instead see Coombes, 2007; Ducker, 1994; Moller, 1996; and Taiepa, *et al.*, 1997). Instead, this study seeks to investigate the area of primary concern for Te Roopu Raranga Whatu o Aotearoa, which involves harvesting methods. Different methods of harvest, both traditional and non-traditional were investigated (**chapter two**), and as an aside, an additional study was undertaken looking at the impacts that ungulate herbivores such as goats may have on kiekie regeneration (see **chapter three** for more background on this). Due to the lack of quantitative data regarding human impacts on kiekie, an important objective in this study is to test whether science can support the tikanga of traditional methods of harvest, and validate the concerns of weavers regarding the poor recovery of kiekie when harvested with non-traditional methods.

This study therefore asks the question posed by kaitiaki:

(A) Is tikanga right - do traditional methods of harvest replenish kiekie stocks and have a lesser impact on plant recovery than non-traditional harvest methods?

This was tested at two scales. Firstly, because many stems are connected, it is hypothesised that harvest in general could have an impact on non-harvested stems within the harvested patch (a patch-level effect). However, it is not understood as to what direction the impact is in (i.e. positive or negative). Secondly, at the stem-level it is hypothesised that traditional methods of harvest will allow faster regeneration. However, there are questions as to how the amount of biomass removed affects the overall recovery of the plant, and whether potential seasonal variations in wet and dry weights dictate the level of regeneration.

These hypotheses were partitioned between the objectives of chapters three and four. To test the hypotheses regarding patch-level and stem-level effects, the objectives from **chapter three** were:

1) To quantify the responses of the patch to different harvesting techniques, and to examine the potential long-term effects of harvest of the patch and;
2) To compare the responses of individual stems to the experimental treatments representing different harvesting methods, and assess the impacts of each technique on the regeneration of the stems following harvest.

A second hypothesis was that the amount of biomass removed will affect the level of regeneration; i.e., that an increase in biomass removed will cause a decrease in plant fitness, thus slowing regeneration (the 'costs' of harvest). To test this, the first objective in **chapter four** was:

3) To assess the amount of biomass removed in all of the harvesting treatments, and explore the potential impact on the regeneration of the stems *in situ* (i.e. side shoot development).

An additional aim of Chapter four was to test a hypothesis that there are differences in the harvested material (using the traditional hand wrench) when harvested in different seasons (spring vs. autumn). This included evaluating differences in average leaf length and leaf number harvested. The purpose of this part of the study was to assess the overall value of the material to weavers (the 'benefits' of harvest). Thus, the second objective in **chapter four** was:

4) To quantify the material harvested from the traditional methods (leaf lengths and leaf number), and to assess whether there are benefits for weavers harvesting in one season as compared to another.

The smaller study into herbivory asked the question:

B) What level of resilience does the kiekie have to herbivory (in particular leaf browse), and what is its recovery like?

Although it was not explicitly outlined in the objectives of chapters three and four, the aim was:

5) To investigate the impact of herbivory on kiekie and the potential effects of recovery as measured for the harvest treatments (above).

CHAPTER 2: Sites and Experimental Treatments

2.1 EXPERIMENTAL FIELD SITES

Although kiekie is not considered to be a threatened species[1], the numbers of accessible kiekie patches suitable for harvest are restricted. In the North Island, limited availability is exacerbated by increasing urbanisation and encroachment on remaining forest. In some cases, roopu have observed compromised survival and/or localised extinctions of their kiekie resources due to decreases in forested areas (Paneke Trust, 1990). In the South Island, kiekie does not grow on the east coast south of Kaikoura, but dense patches of the plant are found throughout the Nelson/Marlborough region, extending down the West Coast to Milford Sound (Lord, 1991). Due to the patchy distribution of the plant, harvesters tend to travel long distances to various sites in both islands, placing increasing pressure on the resource.

Selection of the specific experimental sites for this research needed to take into consideration the cultural impact of moving into areas that may otherwise be harvested by weavers, particularly if access to suitable harvest sites is restricted. Additionally, conducting experimental research within any site requires a rāhui, or traditional prohibition on harvest from the sites for the duration of the research. This ruled out a number of sites within the North Island, and on the upper east coast of the South Island. A further consideration was the potential to continue long-term monitoring (up to 10 years at least) in the sites if mana whenua so desired. This would mean a longer rāhui to ensure that harvesting did not impact on the ability to monitor the population.

Following discussions with representatives from Te Roopu Raranga Whatu o Aotearoa, and after permission was granted by Kaitiaki at each site, two locations were selected for fieldwork (Figure 2.1). One location was on the west coast of the South Island at Te Kōtuku-Whakaoka (Lake Brunner) (MOA), and the other in the Kaimai Ranges (KAI), located in the Bay of Plenty in the North Island. Te Kōtuku Whakaoka is toward the plant's southern most limit and the

[1] Source: http://www.nzpcn.org.nz/vascular_plants/detail.asp?PlantID=1947; 19/09/2007

forest there is subject to increasing housing encroachment as the lake area grows in popularity as a holiday destination, and retirement option. In comparison, the experimental site at the Kaimai Ranges sits within regenerating podocarp-broadleaf forest. The area was gazetted as a Forest Park in 1976 (Department of Conservation, n.d), but rural settlement bordering the site, and a DoC track running through it indicates that the area is not without some human impact. Combined, the sites provided a representative cross-section of the preferred habitat of the kiekie. They also covered a number of different issues in relation to climatic variation, forest type, altitude and the potential effects of human encroachment upon the forest habitat.

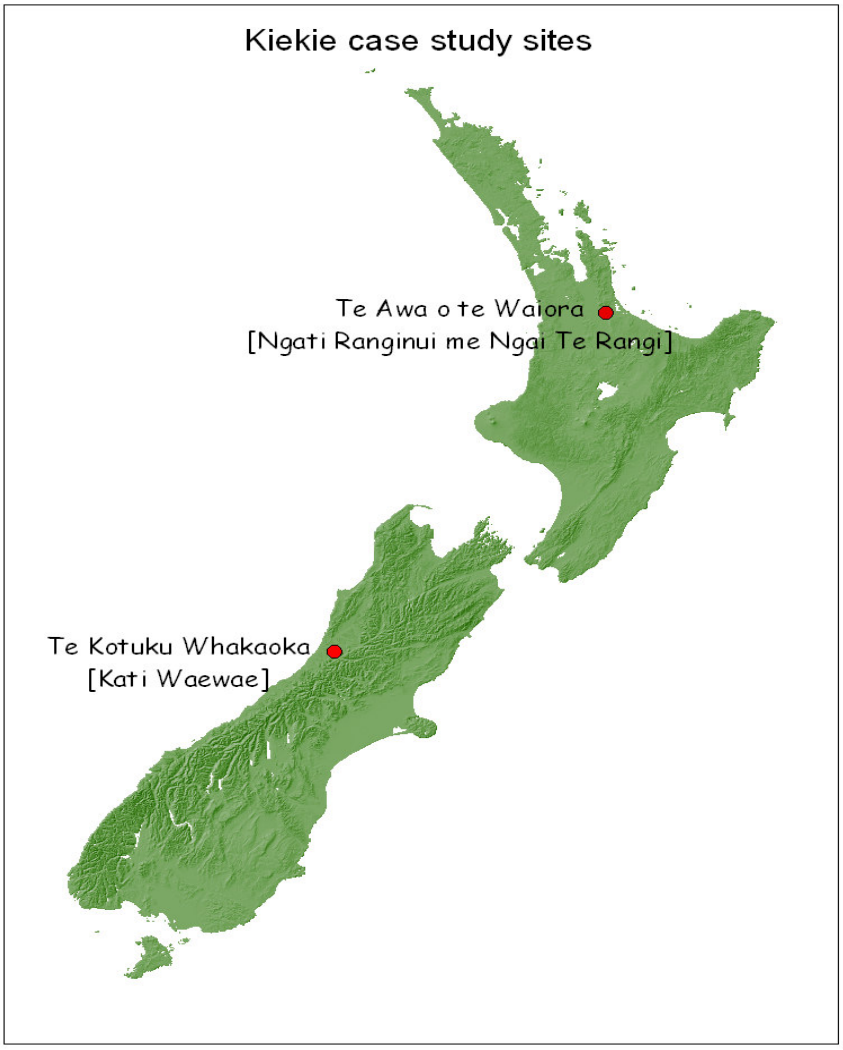


Figure 2.1: Location of research sites (local names) and affiliated iwi/hapu

[Cartographer: H. Pacey, 2006. Base map from Land Information Database, Lincoln University, NZ]

2.1.1 Te Kōtuku-Whakaoka (MOA)

The site at Te Kōtuku Whakaoka - "the diving Kōtuku" - (42^{o} 38.44'S 171^{o} 24.9'E; 110m asl) is located on the lakes' southern-most banks, opposite the township of Moana. The site sits within the DoC managed Mitchells Scenic Reserve - which also contains enclaves of private land - 2km (approx.) before the township of Mitchells. The lake and its environs are of significance to the local hapū, Kāti Waewae, for its many natural resources, including an abundant supply of kiekie, and other rongoa (medicinal) plant resources.

Kiekie are found here in very high density, under a patchy canopy primarily made up of kāmahi (*Weinmannia racemosa)* and hīnau (*Eleaocarpus dentatus*). The majority of the dense patches sprawl along the forest floor, but some were also observed climbing resident hīnau and tōtara (*Podocarpus totara*), at least 6 - 9 m into the canopy.

Figure 2.2: A stem within one of the treatment patches at MOA (South Island), showing the sooty mould and sun spots

The condition of the plants is generally healthy, although there were noticeable leaf defects. The uppermost leaves on many of the leaf heads within the immediate area of thick kāmahi cover are covered by 'black soot' (see Figure 2.2 above), similar to the sooty mould found on tāwhai (Black beech, *Nothofagus solandri* var. *solandri*). Local weavers believe that this may be the consequence of sugars dropping from the flowering kāmahi above (R. Ngarimu; *pers. comm.*). Bright yellow and orange spots ('kiekie-marari'; Anon, 1998) were also noted on the leaves of many plants; particularly those within areas of high irradiance levels. Field observations indicate that these spots may be an indicator of sunlight falling on the leaves as it is filtered through the canopy. Both of the above outlined defects are highlighted more as a concern for the practical application in weaving, but appear to have little impact on the sustained growth and regeneration of the plant. This particular problem was not explored any further within this research, but was acknowledged as an important criterion for plant selection in the experiment methodology.

Figure 2.3: One of the stems in a treatment patch at KAI (North Island). Note that there is no sooty mould, but sun spots do appear on the plants here.

[Photo: S. Scheele, 2007]

2.1.2 Kaimai Ranges – KAI

The Kaimai ranges sit within the rohe of Ngāi Te Rangi and Ngāti Ranginui, and are bordered by three urban centres – Hamilton to the northwest, Rotorua to the southeast, and Tauranga to the east-northeast. The experimental site was located on the summit of the ranges (37^{o} 51.0' S 175^{o} 56.8' E; 450m asl), beside a DoC managed track running along the Piako Stream, off the Old Kaimai Road (within the area of Te Awa o te Waiora – see Figure 2.1). The ranges were once logged for kauri (*Agathis australis*) and mined for gold, but now form part of a popular recreational hunting and tramping area between the Hauraki Plains and greater Bay of Plenty Region (Department of Conservation, n.d).

The forest within the Kaimai Ranges is denser, with a more diverse canopy than that seen at Te Kōtuku Whakaoka. It is dominated by mataī (*Prumnopitys taxifolia*), mixed broadleaf species (tawari- *Ixerba brexioides*, tawa – *Beilschmiedia tawa*, māhoe –*Melicytus ramiflorus*), and some mamaku (*Cyathea medullaris*). Understorey shrubs are also more diverse, with vine species such as tarāmoa (bush lawyer – *Rubus cissoides*), and pikiarero (*Clematis* spp.) found tangled within kiekie patches. As with Te Kōtuku Whakaoka, kiekie in the Kaimai site were generally found clumped within areas of higher light irradiance, along the river and under canopy gaps. Most of the patches within the experimental area were on the forest floor, although some were observed climbing various host trees to heights of 3 - 6 m. Plants also had sun spots on the leaves (Figure 2.3), in addition to lichen coatings and what seemed to be viral leaf infections not witnessed within the South Island site. Overall, the biomass of kiekie appeared to be lower than that at Te Kōtuku Whakaoka. This could be partly the result of past goat browse in the area, which has since been controlled under a new pest management regime by DoC.

2.1.3 Selection of kiekie by weavers and harvesters

Features important to weavers include no or few leaf defects, long leaves, and healthy plants - i.e. no signs of herbivory, lush growth and green leaves with clear definition of the white strips used in weaving (see table 2.1 below). The leaf defects seen at Te Kōtuku Whakaoka (sooty mould and sun spots), and the Kaimai Ranges (sun spots, lichen, leaf viruses) can reduce the value of the plants for weaving due to either: (a) increased effort of weavers in the cleaning and preparation of the leaves; (b) weakened fibres, increasing breakage and wastage; and/or (c) decreased or uneven potential for the fibres to absorb dyes. These caveats do not hold for all weavers, and are strongly dependent on the type of defect (e.g. leaves with obvious signs of herbivory are always avoided). Additionally, the availability of the kiekie within the area, its accessibility, and the time weavers are prepared to dedicate to leaf preparation also affect suitability of plants for harvest (Table 2.1).

Once suitable patches are located, harvesters then adopt a ‘pick one [head], leave one [head]’ method, based on matauranga (ancient knowledge systems) that plants should be left with enough heads for the next harvest cycle (often a year later). The common consensus from

weavers is that harvested plants tend to produce (on average), one or two new side shoots. These shoots then take at least four summers, or harvest cycles, to be at a size suitable for harvesting again.

A reconnaissance visit to Te Kōtuku Whakaoka was undertaken one month previous to the beginning of the field work in 2005. At this visit, a senior weaver gave instruction on appropriate methods of harvest, how plants are selected, and provided additional information with regard to the average number of leaves removed (under a traditional harvest regime), and recovery times of the patch following harvest.

Table 2.1: Criteria used for selection of stems for experimental harvesting

Characteristics	Reasons
• few or no blemishes on the leaves	• some blemishes affect the uptake of dyes; weakening of the fibres associated with yellow spotting
• at a 'pickable height', i.e. ground dwelling • accessible • located in flat terrain	• safety reasons; ease of access • time and safety considerations • safety considerations of the harvesters; prevention of damage to plants caused by harvesters slipping
• large leaf head sizes	• Longer leaf lengths preferred for weaving and tukutuku; smaller plants = more effort to get the same volume; issues for successful regeneration.
• not flowering or fruiting	• plant recruitment purposes

[SOURCES: Paneke Trust, 1990; King & Sweetman, 2001]

2.2 EXPERIMENTAL METHODOLOGY

The experimental unit of harvest was denoted as the leafy biomass removed from the tip of an experimental kiekie stem (Figure 2.4). From the large number of stems within each site, experimental stems were selected for use in the treatments if they fitted the criteria as outlined in Table 2.1 above.

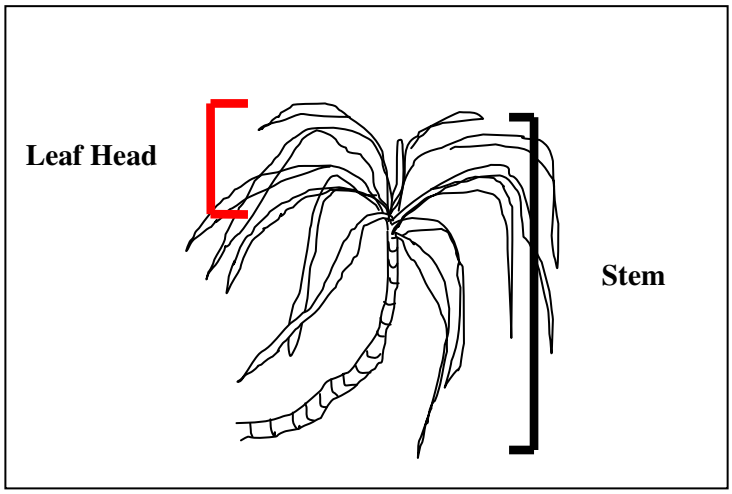


Figure 2.4: Diagram depicting a single kiekie stem. The unit of harvest in this experiment is the leafy biomass at the apex of the stem, also called the 'leaf head'.

Stems that were harvestable had to be individually selected. Due to the vegetative-propagative nature of the kiekie, many stems were found to be connected to other stems via an extensive aboveground and underground rhizome system. These systems are intertwined, highlighting the difficulty in defining independent plants.

For the purpose of this research, ten blocks within the kiekie area were demarcated with at least 10 m between each block to ensure that there was no vascular connection allowing for the transfer of water, mineral nutrients and assimilates between kiekie stems in each block. Within a block, two patches of kiekie stems were then defined as separate groups (patch) of closely intertwined stems. It was assumed that stems within each patch were connected, but were not connected to the stems in the paired group within the block (Figure 2.5). One patch was selected as a 'harvest' or treatment patch, and then paired with a nearby 'control' patch of similar looking plants.

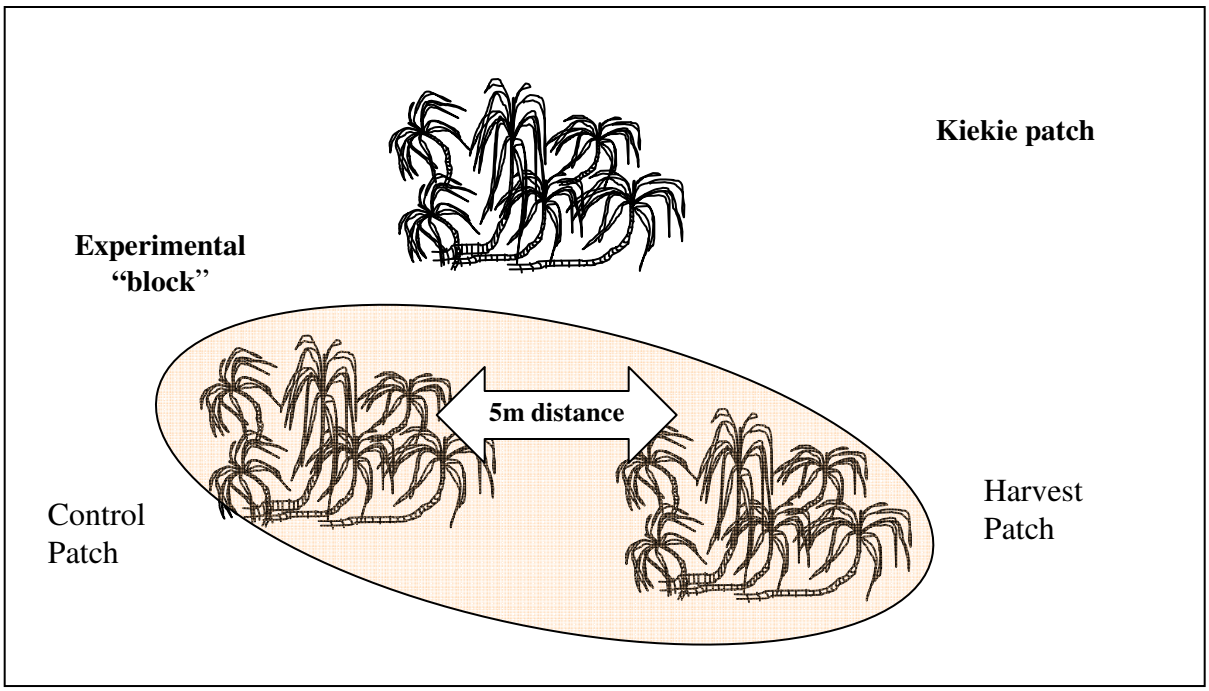


Figure 2.5: A schematic of the experimental design. A kiekie patch was paired with another similar looking patch, 5 m apart, to form an experimental block. One of the patches was designated as the 'harvested' (or treatment) patch, and the other as the 'control' patch. There were ten of these blocks per site.

2.2.1 Harvesting treatments

Within one of the patches within each replicated block, three stems were randomly selected, and then treated with different harvest treatments based on both traditional and non-traditional harvesting techniques. The two traditional techniques involved a tikanga practise of hand wrenching. This technique involves the bending of the tip of each stem using hand pressure, and letting it snap naturally to release (approx.) one third of the leafy biomass. This was done twice – one wrench was undertaken in mid-late spring of November 2005 (labelled "**SW**"), and the second wrench was done during the autumn month of April in 2006 (labelled as "**AW**"). The third treatment was based on a currently adopted non-traditional technique using loppers to remove the entire leaf crown of the stem. This 'full-cut' (labelled as "**AF**") was done at the same time as the AW in April 2006.

Due to feedback regarding examples of severe goat browse on kiekie patches, and questions surrounding the plant's recovery, a fourth treatment was adopted (labelled as "**AH**"). This was undertaken during the autumn treatment period and involved removing half of the leafy biomass with shears. This was based on personal observations of similar effects of goat browse in other locales in the South Island (Figure 2.6). The AW, AF and AH treatments were used to evaluate the effects of three different intensities of defoliation on regeneration, and the AW and SW treatments were used to evaluate the effects of timing of harvest on regeneration.

Figure 2.6: Photographs of the treatments applied to experimental stems (from L to R): (a) Photo one – **SW/ AW** traditional methods of harvest; (b) Photo two – non-traditional **AF** treatment (removal of the entire leafhead); and (c) Photo three – **AH** herbivory treatment.

Finally, two groups of controls were set up to test for patch-level effects after the experimental harvest treatments were applied. In the harvested patch, two stems were randomly tagged as 'control stems- harvested patch' (labelled "**CH**"). These within-in patch controls were assumed to have a vascular connection with the treated stems. In the adjacent control patch, two stems were randomly tagged as 'control stems- control patch' (labelled "**CC**"). Table 2.2 below gives a summary of the treatments and controls.

Table 2.2: Summary of treatments applied to the experimental stems in MOA and KAI over November 2005 (Spring) and April 2006 (Autumn)

Treatment	Summary of treatment method	Fraction of biomass removed	Label Key Codes
***S**pring **W**rench*: using the traditional harvest technique	snapping apex at natural breaking point in spring (November)	One third	**SW**
***A**utumn **W**rench*: using the traditional harvest technique	snapping apex at natural breaking point in autumn (April)	One-third	**AW**
***A**utumn **F**ull-cut*: cutting below leaves with loppers	cut below leaves in autumn (April)	All	**AF**
***A**utumn **H**erbivory*: Cutting through middle of leaf head to imitate goat browse	cut through leaves in autumn (April)	Half	**AH**
***C**ontrol stem in **H**arvested patch*: two non-treated stems in the treatment patch	untreated	none	**CH**
***C**ontrol stem in **C**ontrol patch*: two non-treated stems in a non-treated patch adjacent to the treatment patch	untreated	none	**CC**

2.2.2 Collection of data

Visits to the field occurred every six months for 1.5 years, beginning in November 2005, and finishing with a final visit in April 2007. Data was collected in the field on a number of response variables for all stems. This included leaf and side shoot counts and measurements of leaf lengths and stem circumference. Material was removed as part of the experiment in November 2005 and April 2006, and also in April 2007 which involved the removal of side shoots. All of this material was taken back to the ecology laboratory at the University of Canterbury (UoC) (*ex*

situ methods). The methods and the timing for measurements are summarised in Table 2.3. Full descriptions, results and discussions follow in chapters 3 and 4. Data collected in the field is denoted as "*in situ* methods", and data collected on material removed from the field is denoted as "*ex situ* methods".

Table 2.3: Summary table of experimental methods

Method/ measurement		**t1 (Nov 05)**	**t2 (Apr 06)**	**t3 (Nov 06)**	**t4 (Apr 07)**
In situ (Chapter 3)	*Stem Area (cm^2)*	√	√	√	√
	Leaf lengths (cm)	√	-	CC CH	CC CH
	Count: no. New leaves	-	CC CH AH AW AF	CC CH	CC CH AH
	Count: no. new shoots per stem	-	-	√ (incl: no. leaves p. shoot)	√ (incl: no leaves p. shoot; leaf lengths of longest leaves)
Ex situ (Chapter 4) *(harvested material)*	*Leaf lengths; all leaves (cm)*	SW	AW	-	Shoots: SW AW AF
	Count: Total no. leaves	SW	AW AF AH	-	Shoots: SW AW AF
	Dry & Wet weights (g)	SW	AW AF AH	-	Shoots: SW AW AF

For each time: √ = Method done on all treatments; otherwise codes given for treatments included; "-" = Method not applicable

CHAPTER 3 – Effects of harvest at the patch-level and at the stem-level. (*In situ* measurements)

3.1 INTRODUCTION

As outlined in chapter one clinical observations and experience in the utilisation of the kiekie over the past ca. 1000 years by tangata whenua culminated in guidelines and processes (tikanga) specific to the mediation of human impacts when harvesting (Papakura, 1986). This applied management outlined the most appropriate means of harvesting (hand-wrenching), and the times when to harvest, based on local conditions. For many roopu harvest was best conducted within autumn (Ranui Ngarimu, *pers. comm.*). For some others, the months of late spring to early summer were preferred (Mihinui, 2002).

Following European colonisation of the New Zealand archipelago however, a number of changes led to the breakdown of tikanga. Events which included land confiscation, and the passing of legislation such as the Tohunga Suppression Act (1907) resulted in the weakening, and in some places, a complete loss of matauranga regarding indigenous ecological knowledge[2] In some locales, the tikanga associated with appropriate kiekie harvest was part of the matauranga that disappeared.

The cultural consequence of this loss has been destructive non-traditional harvesting methods by a minority of harvesters. Senior weavers and kaitiaki argue that these methods are counterproductive to 'kaitiakitanga mō te kiekie'. Observations made by kaitiaki indicate that a number of patches are failing, or are slow to recover from harvest as a result of these poor harvesting techniques, such as the removal of most, if not all, of the leafy biomass of stems.

The primary concern of a number of weavers and experienced harvesters, therefore, is the impact of different harvesting techniques upon the sustainability of current stocks of kiekie. Generally, the understanding is that traditional harvesting methods encourages the regeneration of valued kiekie patches. Early work conducted by scientists at the DSIR (Department for

[2] www.teara.govt.nz/The Bush/UsersofTheBush/RongoaMedicinalUseofPlants/5/en; accessed 11:22 am, 29 October 2007

Scientific and Industrial Research) into kiekie harvest during the late 1980s endeavoured to investigate this. Preliminary results did show that traditional methods of harvest appeared to replenish the resource through the promotion of resprouting of harvested stems (Anon, 1988). Unfortunately, these early investigations were of short duration, and the little information published fails to provide any concrete conclusions as to the overall recovery of the plants.

Most temperate vine species are more commonly dependant upon vegetative, rather than sexual reproduction which enables rapid colonisation of suitable microsites (Castellanos, 1991). Early research into the growth establishment of kiekie by Tomlinson & Esler (1974) proposed that damage to the apex would encourage the sprouting of tiny buds found in the leaf scars along the stem, to replace the loss of the leader shoot. A fundamental question then, is whether scientific analysis can support matauranga regarding past kiekie management through the comparison of the abovementioned traditional harvesting methods and timing of harvest, with some contemporary *ad hoc* (non-traditional) ones which result in the complete removal of the leaf head on the stem. If regeneration is encouraged by damage to the apex, what will be the outcome if the entire leaf crown is removed?

Much of the literature regarding the growth and development of climbing plants emphasises that the carbon required for maintaining the competitive growth rates of climbing plants like kiekie, are mostly stored in the expansive leaf crown and root mass (Bell, *et al.*, 1988; Mooney & Gartner, 1991). Rather than diverting valuable resources to stem thickening (as is the case with their tree hosts, and other woody plants), these stores can instead be redistributed to these other facets of the plant (Castellanos, 1991). In some temperate climbing species it has been found that 60% of total shoot dry weight can be allocated to leaves (Hegarty & Cabellé, 1991). Consequently, there will always be some type of physiological adjustment required by the plant due to the removal of these carbon stores through harvest. However, little is understood as to what 'too much removal' might be with regard to the kiekie, and what the true outcome of these non-traditional techniques could be on the vigour of the leaf head and stem. This also raises a further question as to what the impacts may be on the wider patch. Of particular interest are how the remaining stems compensate for the removal of a percentage of the total leaf area, and

whether the percentage removed through harvest is in fact great enough to have an effect (the latter is discussed in more detail in chapter 4).

Secondary to concerns regarding the effect of harvest methods on stem regeneration is the impact of introduced vertebrate pests (e.g. goats) on pā-kiekie (kiekie patches maintained by weavers and their whanau) located within the conservation estate. Goats have been identified as serious pests within native forested areas (Pimm, 1987), are capable of decimating cohorts of palatable low growing shrubs and seedlings and are known to browse on kiekie. The impacts upon kiekie patches can be devastating with field observations confirming the complete removal of the leafy biomass of browsed stems.

This chapter outlines the *in situ* based research into the effects of both traditional and non-traditional harvesting techniques on the sustainability of kiekie patches. This research will test whether harvest using the traditional method encourages vegetative reproduction of the affected stem and patch, thus replenishing, rather than diminishing the resource. On the other hand, it is expected that recovery of non-traditionally harvested stems will be compromised, and stems may even fail to show any signs of regeneration within the 1.5 year time frame of the research. Additionally, a smaller investigation into the effects of goat browse is outlined.

3.2 Objectives

The first aim of this chapter is to test for the impacts of harvest on non-harvested stems within the harvested patch. It is hypothesised that negative effects on stems will result in smaller stem cross-sectional areas, shorter leaves and/or slower production of new leaves. The second aim of this chapter is to determine if there are differences in regeneration between each of the treatments. It is hypothesised that non-traditionally harvested stems will have a poorer survival rate and a slower recovery than traditionally harvested stems. Therefore, the objectives of this chapter are two-fold:

6) To quantify the responses of the patch to different harvesting techniques, and to examine the potential long-term effects of harvest of the patch and;

7) To compare the responses of individuals stems to the experimental treatments representing different harvesting methods, and assess the impacts of each technique on the regeneration of the stems following harvest

3.3 METHODS

The methods outlined in this chapter were undertaken at various times over the 1.5 years of the research period, at both Te Kōtuku Whakaoka and the Kaimai Ranges. Table 3.1 summarises the methods and the times when they were undertaken (This is the '*in situ*' section in Table 2.3 given in Chapter 2).

Table 3.1: Summary of *in situ* methods and times

Method/ measurement		**t1 (Nov 05)**	**t2 (Apr 06)**	**t3 (Nov 06)**	**t4 (Apr 07)**
In situ (Chapter 3)	*Stem Area (cm^2)*	√	√	√	√
	Leaf lengths (cm)	√	-	CC CH	CC CH
	Count: no. New leaves	-	CC CH AH AW AF	CC CH	CC CH AH
	Count: no. New shoots per branch	-	-	√ (incl: no. leaves per shoot)	√ (incl: no. leaves per shoot)

For each time: "√ ", method done on all treatments, otherwise codes given for treatments; " - ", method not applicable

All statistical analyses were performed in the statistical package R version 2.5.1 and in Microsoft Excel 2005.

3.3.1 Measuring patch responses to harvest

Patch-level responses were investigated by monitoring various growth responses of kiekie, and possible changes which could be associated with harvest. Growth responses measured included (1) stem cross-section area growth; (2) the lengths of new leaves produced by the control stems in the harvested and control patches after harvest compared with initial leaf lengths of similar aged leaves at the start of the research; (3) and, the total number of new leaves produced by non-harvested stems over the 1.5 year research period was monitored.

3.3.1.1 Measuring change in stem area

For every stem, the diameter (cm) was measured at a marked point below the leaf head with a diameter tape to the accuracy of +/- 1 mm. This was repeated at every field visit as shown in Table 3.1 above. An ANOVA (Analysis of Variance) test was performed on the November 2005 data set to test for any differences between the area of experimental stems by treatment before harvest.

An ANOVA was used to analyse the change in stem cross-sectional area between November 2005 and April 2007. Percentage of change in stem cross-sectional area was also tested using an ANOVA on the log ratio of change in area between November 2005 and April 2007.

3.3.1.2 Measuring leaf lengths on the Control (CC) and Control Harvested (CH) stems

In November 2005, the first fourteen leaves of each stem tip were marked by flagging tape tied at the base of the bundle. This group was equal to (approx.) half of the mean number of leaves harvested by weavers. In order to ensure consistency at later visits, a knot was tied into the number 15 leaf. Leaves numbered 12 and above were observed to be close to, or at mature length, so measurements were made of the leaves just below the tagged group, that were numbered 15 - 17. These were used as a baseline for subsequent field measurements. At the final field visit in April 2007, measurements were again taken of two groups on all control and Autumn Herbivory (AH) stems:

- The original sample of leaves numbered 15-17 which were >1 year in age; and,

- A sample of leaves ~ 1 year in age in the same relative position on the stem – these were the leaves now numbered 14 – 16 from the tip.

ANOVA tests were used to compare the mean lengths of the three leaves measured in November 2005 (leaves numbered 15 -17), with the three leaves measured in April 2007 (leaves numbered 14 -16).

3.3.1.3 New leaves produced

During April 2006, the total number of new leaves produced by each stem was recorded by reference to the marked fourteen leaves, and the knotted leaf which had been as position 15. This was done for all stems except for the Spring Wrenched (SW) stems which had been harvested in November 2005. In November 2006, leaves could only be counted in the control stems (CC and CH) due to harvesting of the remaining treatment stems in April 2006. By April 2007, the Autumn Herbivory stems had recovered enough to be counted along with the control stems.

A Poisson ANOVA test was used to compare the number of new leaves produced on all of the treatment stems after six months of growth, just before the autumn harvest treatments. Poisson ANOVA tests were also used to compare the number of new leaves produced on each of the measured stems between November 2005 and April 2007. In order to enhance my understanding of how leaf production may vary from season to season, I also plotted leaf totals for each field visit plotted against time to determine if all stems were producing leaves at the same rate over each season.

3.3.2 Measuring stem responses to harvest - Do particular treatments recover better than others?

Stem-level responses were investigated by (1) checking for any stem deaths that occurred and whether particular treatments were more likely to cause stem death than others, and (2) counting

the total number of new side shoots produced on all treatment stems in the period following the first harvest treatment in November 2005. The total number of leaves on each side shoot was also recorded.

3.3.2.1 Measuring stem death

Mortality of the stems was recorded from April 2006 (six months after the first spring treatment) to the end of the research in April 2007. Stems were classified as dead if stem material was brittle and dry, and there was no obvious living leaf tissue. A Chi-square test was used to ascertain if particular harvest treatments were more likely to cause stem death than others.

3.3.2.2 Side shoot regeneration

On those stems that had produced side shoots, tallies of the number of side shoots produced were recorded during each field visit between April 2006 and April 2007. By April 2007, some Autumn Fully-cut (AF) treated stems in the Kaimais had also produced side shoots. In these cases, an additional measurement of the distance (cm) between the cut at the stem apex (as per the treatment outlined in Chapter 2), and the new shoot(s) was made. These measurements were not analysed quantitatively, but provided supporting information with regard to stem and side shoot function. Poisson ANOVA tests were used to compare the number of shoots per stem for each of the treatments.

Total leaf counts were made of the total side shoot leaf count per stem. This was to compare the rate of stem recovery at a fixed length of time (one year) after harvest in both treatments. Shoot leaves on the Spring Wrench stems were recorded in November 2006 (one year after harvest in November 2005), and those on the Autumn harvested stems were counted in April 2007 (one year after the harvest in April 2006). A Poisson ANOVA test was used to compare the mean number of shoot leaves per stem in the two treatments.

3.4 RESULTS

3.4.1 Stem area (cm^2)

There were significant differences in stem cross-sectional area between the two sites and among blocks in November 2005. However, there was no significant difference in stem area among the treatments (Table 3.2 (a)). This showed that random selection of stems for treatments had not introduced any spurious difference among the treatment groups.

An ANOVA test on the change in stem area between November 2005, and April 2007 showed no significant treatment effects (Table 3.2 (b); Figure 3.1). There were significant block and site by treatment effects which were supported by noticeable differences in the means (see table 3.2 (d)). However, five of the twenty Autumn-fully cut treatment stems in the Kaimai site died which will have some impact on these results (see section 3.4.4 for more detail on this). An ANOVA testing for percentage change in stem area using the log-ratio was non-significant, with little difference apparent between all treatment and control stems (Table 3.2 (c)).

Table 3.2 (a): Differences between treatments in the stem cross-sectional area at the start of the experiment in November 2005 (t1), before treatments were applied. Significant p-values are highlighted in bold.

Source	Df	SS	MS	F	*P*
Site	1	13.56	13.56	5.04	**0.03**
Block	18	92.79	5.15	1.91	**0.02**
Treatment	5	3.66	0.73	0.27	0.93
Site x Treatment	5	22.50	4.50	1.67	0.15
Residuals	130	349.53	2.69		

(b): between Nov '05 and Apr '07.

Source	Df	SS	MS	F	*P*
Site	1	2.03	2.03	0.92	0.34
Block	18	184.55	10.25	4.65	**< 0.001**
Treatment	5	11.68	2.34	1.06	0.38
Site x Treatment	5	31.17	6.23	2.83	**0.02**
Residuals	279	615.22	2.21		

Table 3.2 (contd) (c): log ratio of the percentage change in stem cross-sectional area of treatment stems between Nov '05 and Apr '07. Significant *p*-value (< 0.05) is highlighted in bold.

Source					
	Df	SS	MS	F	*P*
Site	1	0.15	0.15	38.91	**<0.001**
Block	18	0.06	0.003	0.91	0.57
Treatment	5	0.02	0.004	0.10	0.42
Site x Treatment	5	0.02	0.004	1.10	0.36
Residuals	119	0.45	0.004		

Table 3.2 (d): Comparison of mean stem area (cm^2) for each of the treatments in the two sites between t1 (November 2005) and t4 (April 2007). Standard deviations are in the parentheses.

Treatments: AF = Autumn Fully-cut; AH = Autumn Herbivory; AW = Autumn Wrenched; SW = Spring Wrenched; CC = control stems in control patch; CH = control stems in harvested patch. Sites: MOA = Te Kotuku Whakaoka; KAI = Kaimai Ranges.

Treatment	Site	t1	t4
AF	MOA	4.95 (0.64)	5.52 (0.85)
	KAI	6.79 (1.70)	5.79 (1.26)
AH	MOA	5.29 (1.17)	5.32 (0.89)
	KAI	6.81 (2.09)	5.64 (1.10)
AW	MOA	6.11 (2.16)	6.23 (2.05)
	KAI	5.35 (0.96)	5.05 (1.12)
SW	MOA	5.59 (1.14)	5.65 (0.96)
	KAI	6.24 (1.29)	5.69 (1.16)
CC	MOA	5.96 (1.71)	6.45 (1.81)
	KAI	6.36 (1.81)	6.00 (1.75)
CH	MOA	5.99 (1.87)	6.12 (1.77)
	KAI	6.30 (2.29)	5.69 (2.0)

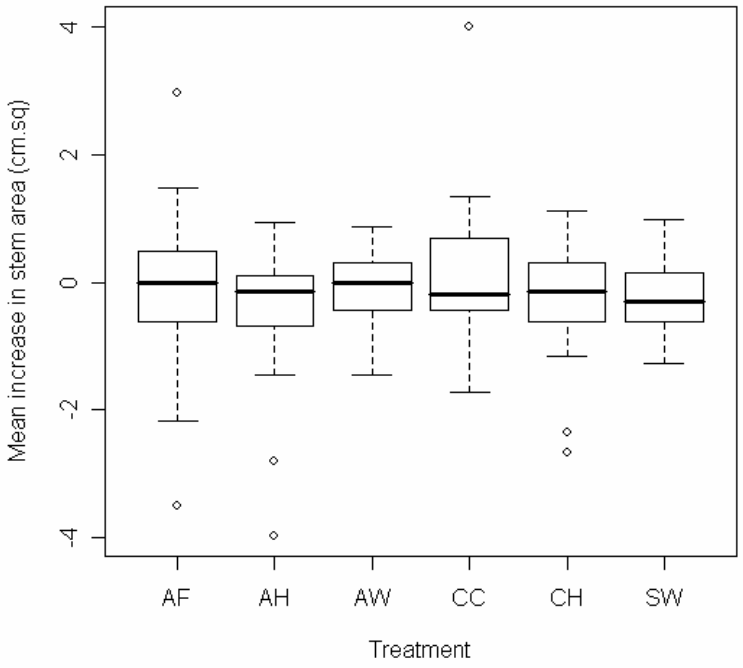


Figure 3.1: Boxplot of mean increase in stem area (cm^2) of all treatments between November 2005 and April 2007. AF = Autumn Fully-cut, AH = Autumn Herbivory, AW = Autumn Wrenched, CC = Control stems in control patch, CH = Control stems in Harvested patch, and SW = Spring Wrenched

3.4.2 Leaf lengths

Results for November 2005 showed strongly significant site and block effects (Table 3.3 (a)), but a non-significant treatment effect indicated that there were no important differences in leaf length between the treatment stems at the beginning of the research. However there was a pre-existing difference noted between the two sets of controls with a lower mean leaf length noted in the Control stems in the Harvested patches (CH) (Figure 3.2; see also table 3.3. (c)). An analysis on the control stems only showed a significant treatment effect (Table 3.3 (b)), indicating that the control stems in the control patch (CC) had a greater mean length on the three leaves measured (leaves 15 – 17), than the control stems in the harvested patch (CH) at the beginning of the research (Figure 3.3 (a)).

Table 3.3 (a): Comparison of the mean leaf lengths of all treatments at the start of the experiment in November 2005 (t1). Significant *p*-values (< 0.05) highlighted in bold.

Source	Df	SS	MS	F value	*P*
Site	1	1179.6	1179.6	12.03	**0.0007**
Block	18	12488.0	693.8	7.073	**<0.0001**
Treatment	5	592.3	118.5	1.21	0.31
Site x Treatment	5	523.2	104.6	1.07	0.38
Residuals	130	12752.2	98.1		

Table 3.3 (b): Comparison of the mean leaf lengths (cm) of the two control treatments (CC and CH) at the start of the experiment in November 2005 (t1). Significant *p*-values are highlighted in bold.

Source	Df	SS	MS	F	*P*
Site	1	1001.80	1001.80	12.05	**<0.001**
Block	18	7267.90	403.80	4.86	**<0.001**
Treatment	1	495.50	495.50	5.96	**0.02**
Site x Treatment	1	0.04	0.04	0.0004	0.98
Residuals	58	4823.00	83.20		

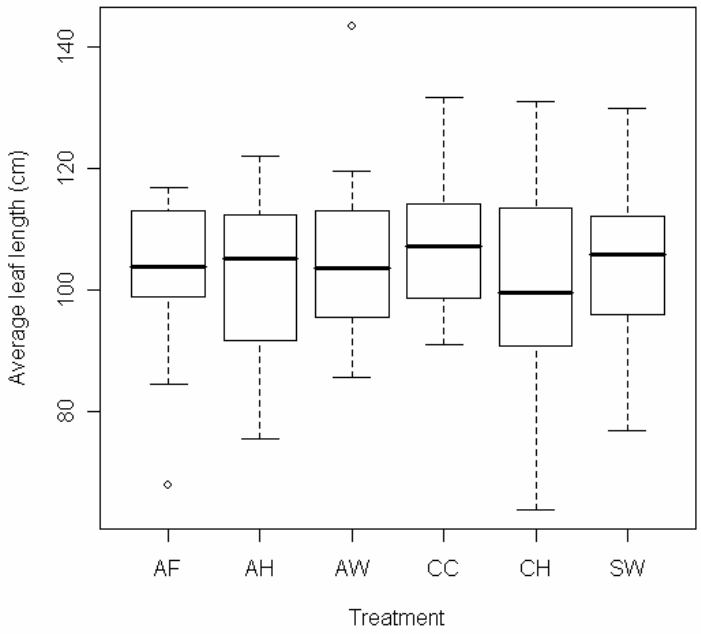


Figure 3.2: Boxplot of the average leaf lengths of treatment stems at the beginning of the research in November 2005 (t1). See later for a closer analysis of the control stems.
AF = Autumn Fully-cut, AH = Autumn Herbivory, AW = Autumn Wrench, SW = Spring Wrench, CC = Control stems in Control patch, CH = Control stems in Harvested patch, SW = Spring Wrench.

Table 3.3 (c): Mean leaf lengths for each treatment stem at the start of the research in November 2005 (t1), highlighting the variation in mean lengths for the controls (CC and CH). [Note: the CH stems at KAI]

Standard deviations are shown in parentheses. MOA = South Island site; KAI = North Island site

Treatment	Site	*t1*
SW	**MOA**	**105.70** (0.62)
	KAI	**101.97** (1.07)
AW	**MOA**	**110.27** (0.37)
	KAI	**99.03** (1.79)
AF	**MOA**	**103.27** (0.70)
	KAI	**103.03** (0.74)
AH	**MOA**	**102.23** (4.70)
	KAI	**102.30** (0.80)
CH	**SI**	**105.48** (0.43)
	NI	**98.37** (0.26)
CC	**SI**	**110.42** (0.68)
	NI	**103.38** (0.45)

The difference in leaf length between CC and CH stems observed in November 2005 increased slightly in April 2007 (Figure 3.3 (b)). However, the total difference in mean leaf length over the 1.5 years of the research was very small (Figure 3.4). An ANOVA test on the difference in mean length showed no significant treatment effect between November 2005, and April 2007 (Table 3.4).

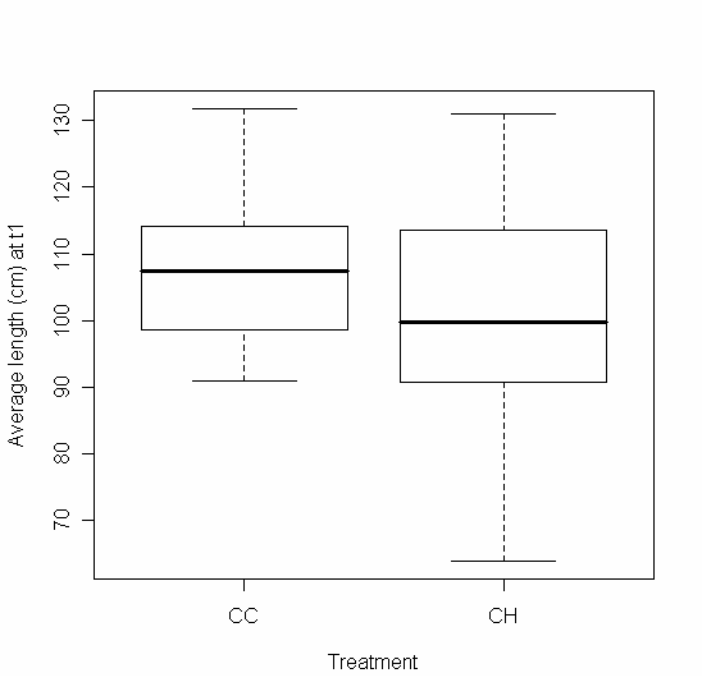


Figure 3.3 (a): Boxplot of the average leaf length (cm) of mature leaves on CC and CH stems in November 2005 (t1).

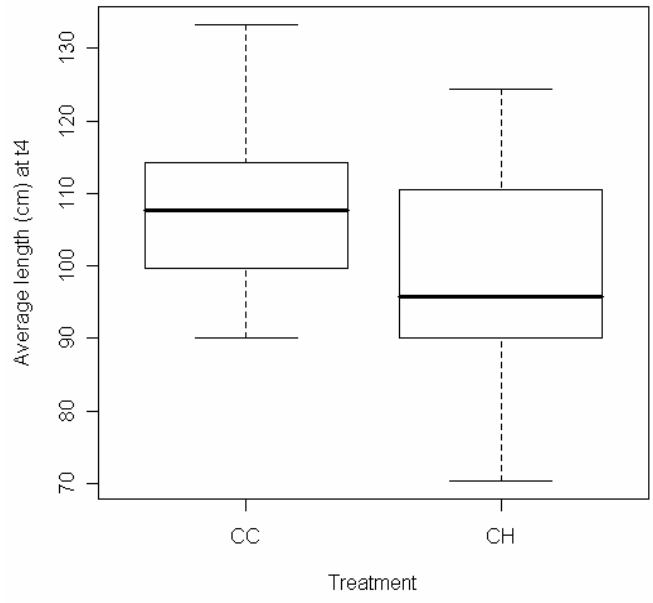


Figure 3.3 (b): Boxplot of the average leaf length (cm) of mature leaves on CC and CH stems in April 2007 (t4).

Table 3.4: ANOVA table summarising the results of the change in average leaf lengths (cm) of mature leaves on the control stems (CC and CH) between November 2005 (t1) and April 2007 (t4) (change = t4 minus t1). The mature leaves are taken as those leaves numbered 15 - 17 at t1, and leaves numbered 14 - 16 at t4.

Source	Df	SS	MS	F	*P*
Site	1	10.81	10.81	0.28	0.60
Block	18	705.45	39.19	0.99	0.48
Treatment	1	112.16	112.16	2.06	0.16
Site x Treatment	1	14.66	14.66	0.37	0.54
Residuals	53	2085.85	39.36		

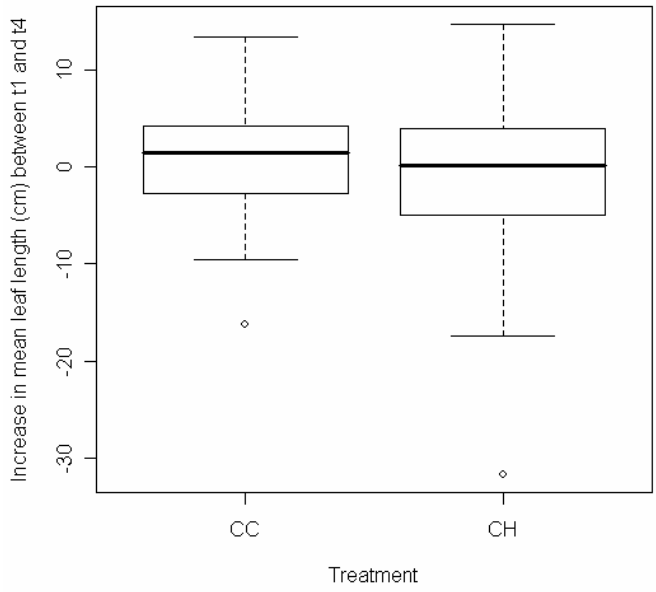


Figure 3.4: Boxplot showing the change in mean leaf length (cm) of the control stems between November 2005 (t1) and April 2007 (t4). CC = Control stems in Control patch and CH = Control stems in Harvested patch

3.4.3 New leaves produced

Results of a Poisson GLM testing for differences in the number of leaves produced by all treatment stems between November 2005 (t1) and April 2006 (t2) (Table 3.5) were non-significant; confirming that all stems were growing at similar rates prior to the autumn

treatments (Autumn Wrench, Fully-cut, and Herbivory) being applied. Spring Wrench stems were not included as they had been harvested in November 2005.

Table 3.5: Summary of results of Poisson GLM comparing the number of new leaves on all treatment stems before conducting the autumn harvest treatments in April 2006 (t2).

Source						
	Df	Deviance	Res.Df	Res. Dev	F	*P*
NULL			150	75.78		
Site	1	2.08	149	73.70	2.08	0.15
Block	18	19.10	131	54.59	1.06	0.39
Treatment	4	1.59	127	53.00	0.40	0.81
Site x Treatment	4	0.82	123	52.18	0.21	0.81

In order to confirm if there was a harvest effect on the patch, a Poisson GLM was used to test for any differences in the number of new leaves produced by the controls in the control patches (CC), and the control stems in the treatment patches (CH) between the start of the research in November 2005 (t1) and at the end in April 2007 (t4). Despite slight differences in leaf number between the two datasets over time (Figure 3.5) the result was non-significant (Table 3.6).

Table 3.6: Summary of Poisson GLM results comparing the number of new leaves produced on the control stems (CC and CH) between November 2005 (t1) and April 2007 (t4). Figures rounded to 2dp, significant p-value highlighted in bold.

Source						
	Df	Deviance	Res. Df	Res. Dev	F	*P*
NULL			74	44.70		
Site	1	1.36	73	43.34	1.36	0.24
Treatment	1	16.30	55	27.05	0.91	0.57
Block	18	2.64	54	24.40	2.64	0.10
Site x Treatment	1	0.03	53	24.38	0.03	0.88

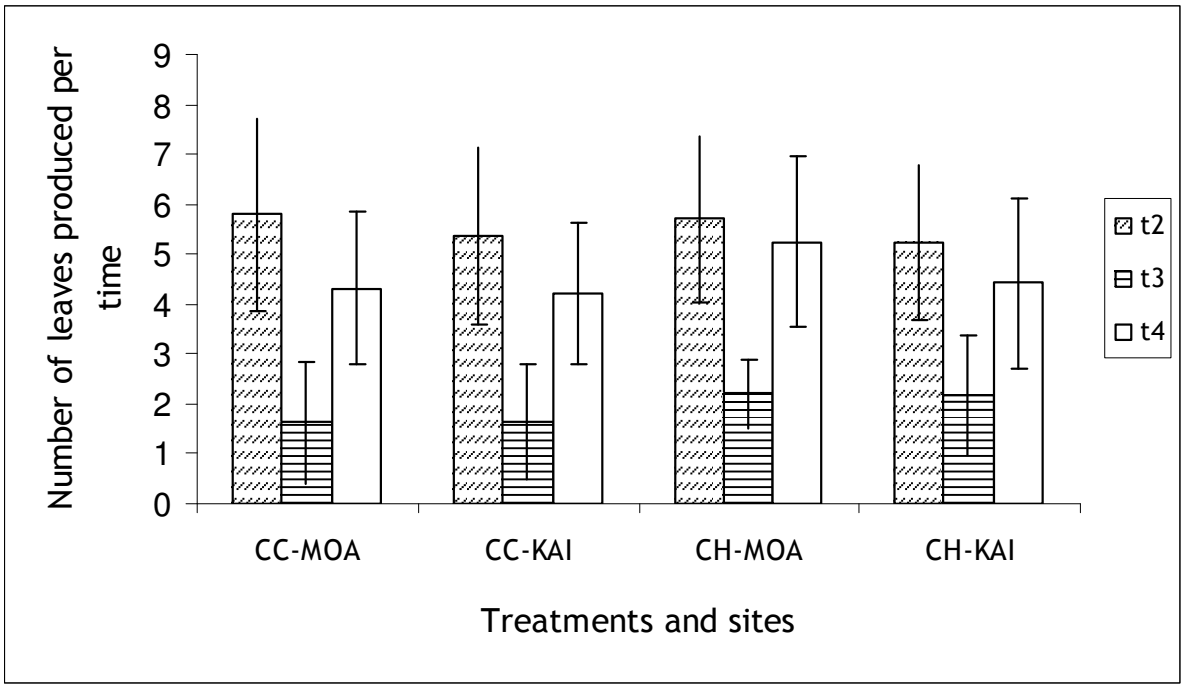


Figure 3.5: Histogram showing leaf production of the two sets of Control stems between November 2005 (t1) and April 2007 (t4). Counts are mean ± s.d. Using the number 15 (knot) leaf, as a reference, new leaves produced were counted at each field visit (approx. every six months). Sites: MOA = Te Kotuku Whakaoka, KAI = Kaimai Ranges. Treatments: CC = Control stems in Control patches, CH = Control stems in Harvested patches. Time periods: t2 = April 2006 (autumn); t3 = November 2006 (spring); t4 = April 2007 (autumn)

The number of leaves produced by the two sets of controls (CC and CH) and the Autumn Herbivory treatment stems were also tested for differences in total number of leaves produced (Figure 3.6). Results were non-significant for the total number of leaves produced over the full 1.5 years of the research (November 2005 – April 2007) (Table 3.7). However, results of a Poisson GLM for the period April 2006 – April 2007 (one year after harvest) were significant for both treatment, and a site and treatment interaction (Table 3.7 (b)). The Control stems in the Harvested patches had the highest mean total number of new leaves (CH; mean = 12.46) (Figure 3.7), although this was only slightly higher than that produced by the control stems in the control patch (CC; mean = 11.5). In comparison the Autumn Herbivory treatment had a lower total mean (mean = 9.82).

Table 3.7 (a): Total number of leaves produced by the Autumn Herbivory (AH), and two Control treatments (CH, CC) between November 2005 and April 2007 (one and half years after harvest). Significant p-value (< 0.05) is highlighted in bold.

Source

	Df	Deviance	Res.Df	Res. Dev	F	*P*
NULL			91	64.98		
Site	1	0.26	90	64.72	0.26	0.61
Block	18	11.67	72	53.05	0.65	0.86
Treatment	2	5.75	70	47.30	2.87	0.06
Site x Treatment	2	6.90	68	40.40	3.45	**0.03**

(b) Total number of leaves produced by the Autumn Herbivory (AH), and two control treatments (CH, CC) between April 2006 and April 2007 (one year after harvest).

Source

	Df	Deviance	Res.Df	Res. Dev	F	*P*
NULL			91	63.13		
Site	1	0.002	90	63.13	0.002	0.96
Block	18	10.74	72	52.39	0.60	0.90
Treatment	2	13.10	70	39.29	6.55	**0.001**
Site x Treatment	2	6.70	68	32.49	3.40	**0.03**

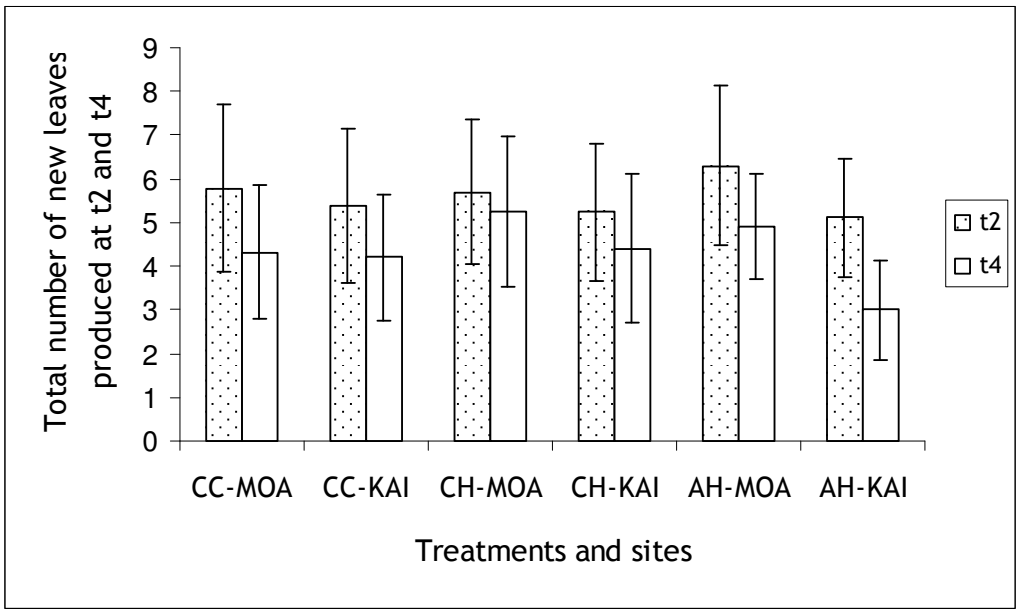


Figure 3.6: Bargraphs of the new leaves produced by the two sets of Controls (CC and CH) and Autumn Herbivory (AH) stems between November 2005 and April 2006 (before harvest treatments were applied); and then between November 2006 and April 2007 when counting of leaves on the Autumn Herbivory treatment could commence again. Sites: MOA = Te Kotuku Whakaoka, KAI = Kaimai Ranges. CC = Control stems in Control patches; CH = Control stems in Harvested patches.

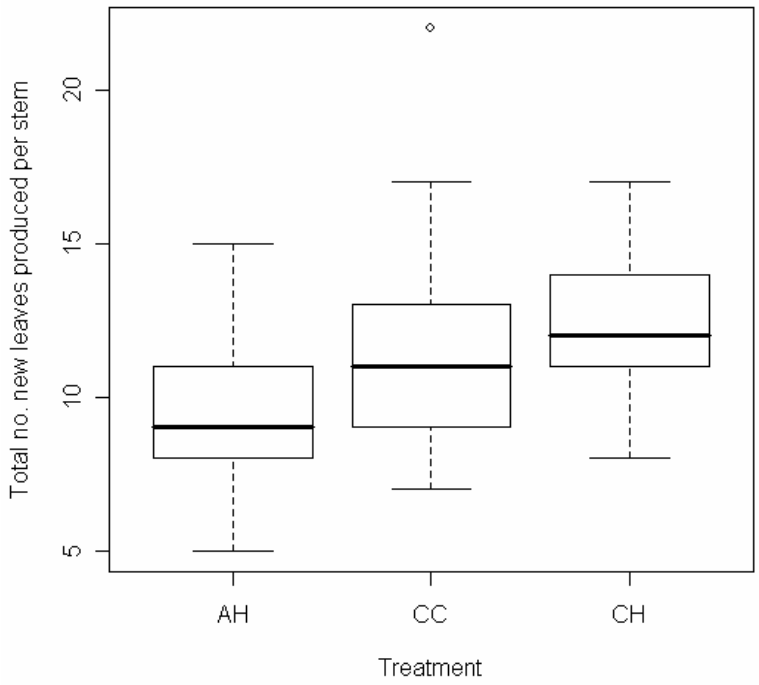


Figure 3.7: Boxplot of the mean total number of new leaves produced per stem between November 2005 and April 2007. AH = Autumn Herbivory treatment, CC = Control stems in Control patch; and CH = Control stems in Harvested patch.

3.4.4 Stem death

A chi-square (x^2) test was used to determine if particular treatments were more likely to cause stem death. Results were significant (x^2 = 13.57, d.f = 5, p-value = 0.02), highlighting that a higher number of Autumn Fully-cut stems died when harvested with this method than with any other treatment (Table 3.8; see also Figure 3.8).

Table 3.8: Results of Chi-square test for differences in stem death between the treatments. Results were significant for the Autumn Fully-cut.

Treatment	Alive	Dead	N
CC	Obs: 38 Exp: 37.25 Cell x^2: 0.02	Obs: 2 Exp: 2.75 Cell x^2: 0.20	40
CH	Obs: 37 Exp: 37.25 Cell x^2: 0.00	Obs: 3 Exp: 2.75 Cell x^2: 0.02	40
AF	Obs: 15 Exp: 18.63 Cell x^2: 0.71	Obs: 5 Exp: 1.38 Cell x^2: 9.56	20
AH	Obs: 19 Exp: 18.63 Cell x^2: 0.01	Obs: 1 Exp: 1.38 Cell x^2: 0.10	20
AW	Obs: 20 Exp: 18.63 Cell x^2: 0.10	Obs: 0 Exp: 1.38 Cell x^2: 1.38	20
SW	Obs: 20 Exp: 18.63 Cell x^2: 0.10	Obs: 0 Exp: 1.38 Cell x^2: 1.38	20
Totals	149	11	160

N = number of treatment stems in the experiment. Obs = the observed number of stems either alive or dead. Exp = the expected number of stems alive or dead.
Treatments: CC = Control stems in Control patch; CH = Control stems in Harvested patch; AF = Autumn Fully-cut; AH = Autumn Herbivory; AW = Autumn Wrench; SW = Spring Wrench

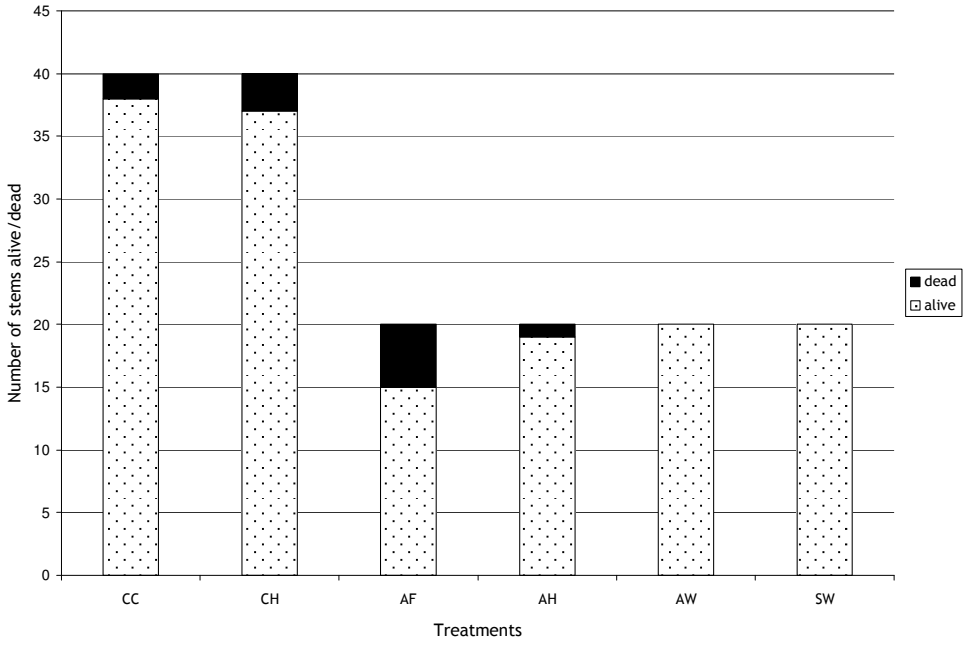


Figure 3.8: Stacked bargraph showing the number of stems alive and dead for each treatment. CC = Control stems in Control patch; CH = Control stems in Harvested patch; AF = Autumn Fully-cut; AH = Autumn Herbivory; AW = Autumn Wrench; SW = Spring Wrench

3.4.5 New side shoots produced on harvested stems

Counts of the number of side shoots produced showed that the two sets of controls and the Autumn Herbivory treatment did not produce any. Mean results of the Autumn Fully-cut, and Autumn and Spring Wrench treatments, showed a slightly higher average for the Autumn Wrenched stems than for the Spring Wrenched. Despite one Autumn Fully-cut stem in the Kaimais producing 24 new side shoots, the treatment produced a poorer average overall (note that the mean = 0.14 without the outlier) (Table 3.9).

Table 3.9: Average number of side shoots produced by each treatment stem. Treatments: CC = Controls stems in Control patch; CH = Control stems in Harvested patch; AF = Autumn Fully-cut; AH = Autumn Herbivory; AW = Autumn Wrench; SW = Spring Wrench.

Treatment	CC	CH	AF	AH	AW	SW
Number of shoots	0	0	1.73	0	2.55	2.35

Tests were done on the treatment stems that had produced side shoots. Results of a Poisson ANOVA for differences in the number of side shoots produced by the Autumn Fully-cut, Autumn Wrench and Spring Wrench was significant for a block effect, and site by treatment interaction effect (Table 3.10 (a)). This analysis included the outlier that produced 24 side shoots (Table 3.11 and see Figure 3.9). However, this was a highly unusual case (due to the general failure of over 50 % of the AF stems to regenerate), so a similar test was done with the outlier removed (Table 3.10 (b)), in order to determine what impact that one case had on the overall results. The result of this test showed a significant treatment effect, highlighting the poor recovery of the other Autumn Fully-cut stems.

Table 3.10 (a): Total number of side shoots produced by each of the harvesting treatments (traditional hand-wrenches, SW and AW, and non-traditional harvest, AF); with the outlier included. Significant *p*-values (< 0.05) are highlighted in bold.

Source						
	Df	Deviance	Res. Df	Res. Dev	F	*P*
NULL			55	148.91		
Site	1	3.69	54	145.21	3.69	0.06
Block	18	52.04	36	93.18	2.89	**<0.0001**
Treatment	2	3.48	34	89.70	1.74	0.18
Site x Treatment	2	42.15	32	47.56	21.07	**<0.0001**

(b) Outlier removed

Source						
	Df	Deviance	Res. Df	Res. Dev	F	*P*
NULL			53	77.52		
Site	1	0.006	52	77.51	0.006	0.94
Block	18	10.01	34	67.50	0.56	0.93
Treatment	2	41.00	32	26.50	20.50	**<0.0001**
Site x Treatment	2	6.27	30	20.23	3.13	**0.04**

Table 3.11: Table of mean number of side shoots per harvest treatment for each site. Figures in bold are mean ± s.d.
Figure in the parentheses is the mean of the AF for KAI when the stem that produced 24 side (mean indicated with *) is removed. Sites: MOA = Te Kotuku Whakaoka, KAI = Kaimai Ranges. AW = Autumn Wrench, SW = Spring Wrench, AF = Autumn Fully-cut.

Treatments	MOA	KAI
SW	**2.3** ± 0.82	**2.4** ± 1.35
AW	**3.1** ± 1.10	**2** ± 1.05
AF	0	**3.86*** ± 8.90 (**0.5** ± 0.55)

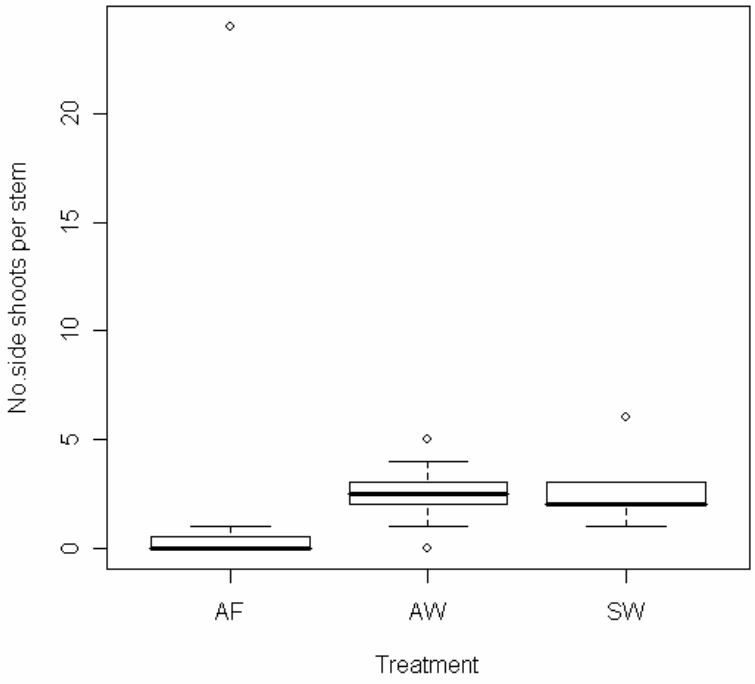


Figure 3.9: Boxplot of the mean number of side shoots produced by each of the harvest treatments. AF = Autumn Fully-cut (non-traditional method), and traditional methods, AW = Autumn Wrenched, and SW = Spring Wrenched.

A test for differences in the number of side shoots produced by the traditional wrench treatments only, gave a non-significant result, indicating that there was little difference in recovery between the two (Table 3.12).

Table 3.12: ANOVA table summarising the results of comparisons of the total number of side shoots produced by each of the traditional hand wrench treatments – Spring and Autumn Wrench. Test was non-significant

Source	Df	Deviance	Res. Df	Res. Dev	F	*P*
NULL			39	21.47		
Site	1	1.02	38	20.45	1.02	0.31
Block	18	5.62	20	14.82	0.31	1.00
Treatment	2	0.16	19	14.66	0.16	0.69
Site x Treatment	2	1.39	18	13.27	1.39	0.24

3.4.6 Number of leaves on side shoots per stem

The total number of side shoot leaves per treatment stem (one year after harvest) was tested for the traditional hand-wrenching techniques (SW and AW) only, due to the rarity of Autumn Fully-cut side shoots in both sites. Results showed strong treatment, block and site by treatment interaction effects (Table 3.12). On average, there were more shoot leaves on the Autumn Wrench stems than on Spring Wrench (AW (mean) = 32.11; SW (mean) = 26.9). There was also a large difference noted in treatment means in Te Kōtuku Whakaoka (average number of leaves for AW = 36, SW = 23.7). In the Kaimai Ranges site, this difference was not as pronounced, and in contrast to Te Kōtuku Whakaoka, side shoots from the Spring Wrench stems had the greater average (average number of leaves for AW = 27.78; SW = 30.1) (Figure 3.10).

Table 3.13: ANOVA table summarising results of the total number of leaves on all side shoots per treatment stem, one-year after harvest. Significant p-values (< 0.05) are highlighted in bold.

Source	Df	Dev	Res. Df	Res.Dev	F	*P*
NULL			38	402.47		
Site	1	0.24	37	402.24	0.24	0.62
Block	18	120.99	19	281.25	6.72	**< 0.0001**
Treatment	1	10.30	18	270.94	10.30	**0.001**
Site x Treatment	1	15.72	17	255.23	15.72	**< 0.0001**

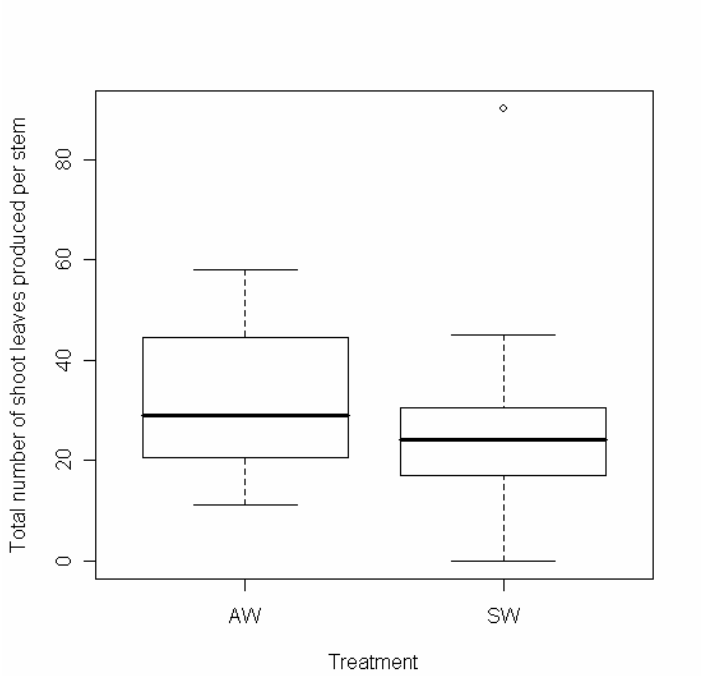


Figure 3.10: Box plot of the number of leaves produced on new side shoots, per stem; one year after harvest. AW = Autumn Wrenched and SW = Spring Wrenched

3.5 DISCUSSION

3.5.1 Patch-level responses to harvest

Due to the important role played by stems in the transportation and storage of resources, there were questions as to the potential effects of harvest on stem cross-section area by removing the leafy biomass. In the research of individuals such as Francis Putz (1983, 1990) it was found that stem cross-sectional area scaled positively with leaf area in lianas. Therefore, if the function of the stem as a means of transporting water and minerals to the leaf crown is made redundant through the removal of portions of (Spring, Autumn Wrench and Autumn Herbivory treatments), or the entire leaf crown (as in the Autumn Fully-cut treatment), will the stem cross-sectional area change accordingly? There was also a question as to whether harvesting in general may cause a change in stem cross-sectional area of unharvested stems following the decrease in total leaf area of the patch. Analyses showed that there were no significant differences between

the controls and treatment stems by the conclusion of this research in April 2007, demonstrating that harvesting in general did not appear to have an observable effect on the stem cross-sectional area of stems in the patch. Furthermore, diameter growth did not appear to be compromised and/or enhanced by any particular treatment when compared with the growth of the two sets of controls, although the short-time period over which this research was conducted makes it difficult to set any firm conclusions about this.

A further consideration was whether harvest may cause a change in the average leaf lengths in the Controls in the Harvested patch (CH) over time, as a response to harvest within the patch. Longer leaves (> 90 cm) are preferred for some forms of weaving, and so length affects the overall quality of stems within the patch for weavers. Results of a change in average leaf length were non-significant. Although there were some differences noted between the two control sets in April 2007, this disparity was also noted at the start of the research in November 2005. Consequently, as far as I could detect, it did not appear that there were any direct effects of harvest on the leaf lengths. Nor were there any effects of harvest on the number of new leaves produced by the Control stems in the Harvested patch when compared with the Control stems in the Control patch.

Overall, there appeared to be no observable effects of harvest on the wider patch. However, the difficulties in defining a true patch, versus a collection of independent stems may factor into the results seen in this part of the research. The issues in identifying individual climbing plants have been the bane of many researchers (Gerwing, 2004; Mascaro et al, 2004), due to the problems in correctly identifying ramets, genets and branches. In this research, without doing an invasive assessment of the underground biomass first, it was assumed that patches of closely intertwined kiekie stems were connected. As much as I have tried to counter the possibilities of randomly selecting individuals within the patches, there is the potential that results are not as indicative of a patch-level effect because of this.

3.5.2 Stem-level responses to harvest

The ability to regenerate is a characteristic of all vine species (Schnitzer, *et al.*, 2004), and is key to ensuring their persistence within forest ecosystems (Bond & Midgley, 2001). Because they are unable to support themselves to the considerable heights they can reach (sometimes up to 30 m into the canopy), lianas are heavily dependant upon mature tree hosts which are prone to eventual collapse (Putz, 1983). If the damage sustained through a fall is severe enough to sever the leader shoot from the stem, the plant will recover from the damage by the release of dormant lateral buds located along the length of the stem, producing replacement ramets, or side shoots that are genetically the same as the parent stem (Fisher & Ewers, 1991; Putz & Holbrook, 1991; Tomlinson & Esler, 1974). Because the stem can also act as a secondary photosynthetic organ, and as a store of starch, recovery is possible if defoliation occurs (Givnish & Vermeij, 1976). However, removing all of the leaves on a stem, and reducing the available carbon stores to the rest of the plant has been shown to retard regeneration via side shoot production, due to the lack of those resources for growth (see chapter 4 for more analyses on this). These theories were supported in the results. The two traditional methods of hand-wrenching (Spring Wrenched and Autumn Wrenched) produced more side shoots on average than those of the non-traditional Autumn Fully-cut treatment (means = 2.55, 2.35 and 1.73 respectively). An additional analysis on stem morbidity showed that a higher number of Autumn Fully-cut stems died after the application of the treatment, than any other harvest method ($x^2 = 13.57$, d.f = 5, p-value = 0.02).

Much like the Autumn Fully-cut stems, the Autumn Herbivory stems did not appear to fare as well as the traditional hand wrench stems. Results of analyses on recovery one year after harvest (April 2006 to April 2007) showed that the Autumn Herbivory stems did not vegetatively regenerate, and strongly significant results showed that they produced a lower average output of new leaves when compared to the two sets of control stems one year after harvest. In the literature, it is argued that much of the dry weight in lianas such as the kiekie is allocated to their expansive leaf crowns (Teramura, *et al.*, 1991). Further increases to leaf area, either through the expansion of leaf lengths or the production of new leaves enhances exploitation of light resources. This allows stems to maximise their growth (via photosynthetic production), and repress competitors through shading (Givnish & Vermeij, 1976). Increasing the number of

leaves also improves the chances of a liana colonising more of its preferred microhabitats, and thus, maintaining its abundance within parts of the forest (Baars & Kelly, 1996). As the results showed, removal of leaves can suppress any competitive advantages of the affected stems. In the Autumn Herbivory treatment, leaf lengths were halved to mimic a goat browse. Consequently, the reduction in length would have lowered photosynthetic activity, potentially slowing the uptake of carbon and hence, the rate of new leaf production.

Results of this part of the study indicated that recovery after harvest is sped up when using a traditional hand wrench method, supporting the tikanga about kiekie management. Both sets of the traditionally hand-wrenched treatments showed regeneration within a one year time frame, supporting the findings of Putz (1984) who found that damaged vines in Panama resprouted within 8-12 months. These results are also in line with, and build upon the conclusions drawn by the limited earlier work on kiekie regarding the replenishment of stems after harvest (Anon, 1988).

There does appear to be an indication that Autumn Wrench stems may be more competitively advantaged. A significant result for the total side shoot leaves per treatment stem demonstrates that the Autumn Wrenched stems have more total shoot leaves per stem one year after harvest (Autumn Wrench shoot leaves = 32.1 per treatment stem vs. 26.9 shoot leaves per Spring Wrench stem). A wider analysis on regeneration and plant recovery will be continued in Chapter 4.

In many of the analyses, there was some evidence of natural variability within the population. Results highlighted significant differences within the sites (i.e. between blocks), and between the sites themselves, suggesting that one site (the Kaimai Ranges) may have more of the microhabitats that are favoured for enhanced growth, than the other site (Te Kōtuku Whakaoka). Milder winter temperatures are considered by some researchers to be more favourable to the growth and distribution of lianas, due to the reduced threat of freezing-induced embolism (Londré & Schnitzer, 2006). Because the kiekie is an evergreen, and carbon gain can potentially occur all year round, a warmer climate is also more supportive of enhanced regeneration after harvest (Chabot & Hicks, 1982). The Kaimai Ranges are further north than the site at Te Kōtuku

Whakaoka, and are therefore, not subject to the same winter temperature extremes as might be found in the South Island. It is possible then, that this could have some bearing on the results; though site and block effects were factored into the analyses, allowing me to measure treatment effects despite these factors. What it does highlight however, is the importance of carefully interpreting the information as related to local environment. This is necessary when evaluating the role of this research as compared to tikanga.

3.6 SUMMARY

In order to meet the responsibilities of kaitiakitanga mō te kiekie, weavers and harvesters are dependant upon good information that ensures the appropriate utilisation of kiekie. As argued by many, good practice and careful observations made over generations and embedded within tikanga have appeared to replenish rather than diminish the resource. There is an indication that stems and the wider patch can recover from all forms of harvest, but the rate of recovery is affected by the mode of harvest.

This part of the study supports traditional knowledge regarding harvest in a couple of ways. Firstly, hand wrenching promotes vegetative reproduction within patches, which supports continued utilisation of the resource by weavers undertaking this traditional practice. This is because the removal of the leaf head (the apex) provides a cue to the plant to resprout. Secondly, there is now some quantitative data to support the tikanga of seasonal harvests. For higher latitudes such as the Kaimai Ranges, results showed that the spring wrenched stems can recover well. However, if we consider the greater leaf area of autumn wrenched side shoots (in terms of leaf number) it does indicate that autumn wrenching may have the competitive advantage in the long term.

CHAPTER 4 – The Costs of Harvest to the Affected Plants and the Benefits for Weavers (*Ex situ* measurements)

4.1 INTRODUCTION

Removing biomass through harvest is expected to have some impact on plant recovery. Although much of the literature referred to in this study is based on herbivory, the concepts are much the same for human harvest. Therefore, the response of a plant in terms of degree, and direction (i.e. positive or negative) is dependent on the type of damage (Strauss & Agrawal, 1999); the ability of the plant to either tolerate or compensate for the defoliation (Hawkes & Sullivan, 2001); and also, on the amount of biomass removed (Raghu, *et al*., 2006). A plant that is defoliated has two likely responses. It may recover, although the actual success of this is highly dependent on both the percentage and spatial distribution of the damage (Avila-Sakar & Stephenson, 2006). Alternatively, the plant might die. The direction a plant can move along this continuum is then contingent on the answers to two questions. Firstly, how many resources are available to the plant soon after damage? and secondly, how fast can those resources be diverted to the damaged area?

The first question in the context of this research – how many resources are available after damage? - pertains to earlier research into vines which argues that the leaf crown holds a substantial percentage of the plant's reserves (Castellanos, *et al.*, 1992). In removing a given percentage of aboveground biomass, therefore, the expectation is that the fitness of the plant will be reduced due to the loss of those stores and photosynthetic material (Raghu *et al*., 2006). Consequently, as the percentage removed is increased, the ability of the plant to compensate should also decrease; that is, plant recovery should decrease with increasing biomass removal.

However, the predictions of recovery are not as straight forward when based solely on biomass removed. This is due to the interplay of factors including spatial distribution of the damage and the types of plant structures affected (Avila-Sakar & Stephenson, 2006). In climbing plants the mechanisms for structural damage repair already exist as a tolerance to tree fall and other risks associated with the highly heterogeneous environments in which they live (see chapter 3). More

specific investigations into kiekie indicate that stem injury can be compensated for via vegetative reproduction (Tomlinson & Esler, 1974). In this regard, I expect that the effect of harvest (and the associated stem damage) can be mediated to a degree through these same repair pathways. However, there is a question mark regarding the impacts of defoliation alone. This study is the first investigation into the recovery of kiekie after mammalian herbivory.

The second question - how fast can available resources be diverted to the damaged area? – relates to the plant's stores remaining after harvest/ herbivory and the resource conditions before. In terms of herbivory, the empirical evidence regarding plant recovery under different resource conditions generally concludes that recovery from herbivory is best during high resource conditions (Chabot & Hicks, 1982). As Christine Hawkes and Jon Sullivan (2002) found though, there are models which dispute this generalisation, and instead argue that recovery is best achieved under low resource conditions. No matter the argument, it is expected that kiekie regeneration will be variable between seasons; the question is whether the differences in resource availability will correspond to a similar difference in recovery after harvest.

The growing season of kiekie has not been studied extensively, but it is presumed that growth is initiated around the start of spring (early – mid September) (Godley, 1979).This is the period when reserves stored within its leaf crown are expended for the new flush of growth. As the season shifts into summer (early – mid December), nutrient stores are gradually replenished and then used for assimilation of carbon into carbohydrates to be stored for the winter dormancy period (beginning around June – July). Wet matter to dry matter ratios fluctuate during this cycle, and it is predicted that the winter period will likely be the time when stems are at their heaviest for both wet and dry weights.

According to the arguments presented earlier regarding enhanced recovery under high resource conditions, we would expect that the recovery of kiekie stems harvested in spring will be greater than those harvested in autumn. If defoliation occurs during cooler months (i.e. autumn) it is also expected that affected plants would have less opportunity to immediately replace lost stores as efficiently as those harvested in spring. Regeneration of these stems should therefore be slower. The new biomass produced (side shoots) would also be expected to be lower. However, because there have been no general patterns confirmed with regard to plant-herbivore

interactions (in this context, plant-harvest interactions), the recovery of the stems in this research could potentially go either way.

This part of the research investigates the cost of harvest to the plant in terms of the time to regenerate. It also aims to clarify if a variation in resource conditions pre-harvest will affect the rate of kiekie recovery, and whether the removal of an increasing amount of biomass will correspondingly decrease the recovery of harvested kiekie stems (see chapters 2 and 3). Information from these provide valuable clues as to how recovery may differ between treatments, and also present a timeline of growth from 1 year (Autumn Wrench side shoots) to 1.5 years (Spring Wrenched side shoots), to enhance our currently limited understanding of kiekie growth and development.

This chapter also looks at the overall value of the harvested material to weavers, and assesses if efficiency is enhanced by harvesting in one season as compared to another time of the year (spring vs. autumn). 'Efficiency' is defined in the context of this study as a greater amount of quality material (in terms of greater average leaf lengths and leaf number) harvested, for the least effort. Least effort in this regard only explores the potential differences in material removed when harvested at different times of the year. To try and answer this, a comparative analysis was made of length and leaf number for each of the traditional methods of harvest only – as the methods adopted under tikanga - and investigated whether 'least harvesting effort' was achieved at one or the other of the harvesting times, or if they are both the same. This research does not explore the varying degrees of effort that are associated with preparation of the leaves for weaving. This process can be lengthened by the amount of moisture contained within the leaves, and requires a separate investigation. However, the overall costs associated with this will be considered in the general discussion in Chapter 5.

4.2 Objectives

In chapter three, an analysis was made of the recovery of treated stems following harvest in terms of regeneration, and of the response of the non-harvested stems in the harvested patch to harvest. This chapter examines the costs to the harvested stems in terms of the amount of

biomass removed. In this regard, this part of the research serves to establish if the amount of biomass removed dictates (1) how well a plant can recover, and (2) whether it is a good indicator of the potential delay in regeneration of the stem as indicated by the expectations of resource conditions and compensation outlined above (section 4.1).

To summarise, the objectives of this chapter consider both the costs to the plant of harvest, and the benefits to weavers measured by the quantity and quality of useful material that may be associated with harvest season.

(1) To assess the amount of biomass removed in all of the harvesting treatments, and explore the potential impact on the regeneration of the stems *in situ* (i.e side shoot development); and,

(2) To quantify the material harvested from the traditional methods (leaf lengths and leaf number), and to assess whether there are benefits for weavers harvesting in one season as compared to another.

4.3 METHODS

The methods outlined in this chapter were conducted at various times over the 1.5 years of the research period at both Te Kōtuku Whakaoka and the Kaimai Ranges. All material harvested from the field was taken back to the lab within the School of Biological Sciences, University of Canterbury. Table 4.1 summarises the methods and the times when they were undertaken (This is the *ex situ* section outlined in Table 2.3, chapter 2).

Table 4.1: Summary of *ex situ* methods and times

Method/ measurement		**t1 (Nov 05)**	**t2 (Apr 06)**	**t3 (Nov 06)**	**t4 (Apr 07)**
***Ex situ* (Chapter 4)** *(harvested material)*	*Leaf lengths; all leaves (cm)*	SW	AW	-	Shoots: SW AW AF
	Count: Total no. leaves	SW	AW AF AH	-	Shoots: SW AW AF
	Dry & Wet weights (g)	SW	AW AF AH	-	Shoots: SW AW AF

For each time: √ = method done on all treatments, otherwise codes given for treatments included; **" – "** Method not applicable

All statistical analyses were performed in the statistical package R version 1.5.1 and Microsoft Excel 2005.

4.3.1 Measuring leaf lengths of traditionally hand-wrenched methods

Ten Spring Wrenched (SW) stems were harvested from each site in November 2005. All leaves removed were measured and recorded for length, with leaf number one denoted as being the first

leaf of ≥10 cm at the stem tip. In April 2006, ten Autumn Wrenched (AW) stems were harvested from each site. Leaves were measured as for the Spring Wrenched stems. An ANOVA (Analysis of Variance) test was used to analyse the leaf lengths to establish if there were any differences between treatments. An additional analysis was undertaken to determine the range of leaf lengths. All leaves ≥10 cm were divided into five length classes: (a) 10 – 30 cm; (b) 31 – 60 cm; (c) 61 – 90 cm; (d) 91 – 120 cm; (e) 121 – 150 cm. Because leaf length dictates the weaving output that can be achieved with a particular leaf size, these size classes are to highlight for weavers any relative differences in harvested leaf material that might exist between each treatment. As some of the major forms of weaving such as tukutuku and whariki require long leaves (at least over 90 cm), a Poisson ANOVA was used to test for any differences in the number of leaves over 91 cm between the two treatments.

4.3.2 Counts of leaves harvested

Counts were made of the number of leaves removed in all of the harvest treatments, including the Autumn Fully-cut (AF) and Autumn Herbivory (AH). A Poisson ANOVA test was used to compare the total number of leaves removed. Final evaluation of the results was conducted with two outcomes in mind. Firstly, assessing leaf number harvested using the traditional methods and the overall benefit to weavers; and secondly, assessing the cost of harvest to the stems, in terms of biomass removed (see also next section).

4.3.3 Dry and Wet weights

For each harvested stem, total wet (fresh) weights were recorded. Leaves were stripped from stem material, and measured for leaf length, before being weighed and then bagged. Material was dried for 6 days at 70^{O}C. At the end of the drying period dry weights were recorded. An ANOVA was used to assess for differences in the dry weights between each treatment. A further analysis was conducted on the change in relative water content (loss of weight on drying divided by the wet weight) to ascertain if all treatments had the same water content. Since I did not record the weights of leaves and stem material separately for the Spring Wrench harvests, the

allocation of weight to stem vs. leaves could not be tested for each treatment, although data on this are available for the autumn harvest treatments.

Dirt was not removed from the original set of Autumn Wrench stems before I weighed them (wet weights), and so I took another sample of stems from the field to assess what effect this may have had on the data. Five stems were randomly harvested in each site on the periphery of the experimental blocks, using the same criteria selected for the original harvest treatments (see Table 2.1 – section 2.1.3). The leaves and stems were weighed before they were shaken to remove debris and then thoroughly cleaned in tap water, in order to estimate the extra weight present in dirt and litter on the stems. Results of the weight differences before and after dirt removal showed a large enough difference to change the data, and so these were then used to correct the Autumn Wrench wet weights before statistical analysis.

4.3.4 Measuring the biomass of the regrowth (side shoots) on traditionally harvested stems

In April 2007, counts were made in the field of the number of new side shoots produced by the experimental stems, and the total number of leaves per side shoot, per stem. I assumed that all leaf-like structures were leaves (including what might be the early development of leaf scales), and thus counted all "leaves" $\geq$ 1 cm in length.

Measurements for length were also taken of the three longest leaves on each side shoot. The lengths of the three longest leaves on all side shoots were summed for each treatment stem, as was the total leaf number on all side shoots.

The largest side shoots produced on each of the harvested stems were removed from the field and taken back to the laboratory for analysis. By removing the larger side shoots, I was able to measure the maximum regrowth equally on all stems. For each of the removed shoots, all of the leaves were counted, and then individually stripped from the leaf bundle and measured for length. Shoot leaves were then weighed and bagged separately before drying at 65^{o}C for 6 days. After drying, the leaves and stems were again weighed.

ANOVA tests were used to compare differences in wet and dry weights, and the total leaf length (cm) between each treatment stem. Additional ANOVA tests were done on the differences in the change in weight after drying and the relative water content. A Poisson ANOVA was used to compare total shoot leaf number per treatment stem.

The side shoots on the Spring Wrench stems had an extra six months of growth than the side shoots of the Autumn Wrench stems when they were harvested and brought back to the lab. Therefore, because the Spring Wrench side shoots are at 1.5 years of development and the Autumn Wrench side shoots are only at 1 year of development, there is an expectation that there will be a treatment effect for most, if not all of the analyses. However, I am interested in seeing the scale of the difference, and then using this information to further determine how biomass removal affects the recovery of the affected stem.

4.4 RESULTS

4.4.1 Leaf lengths of traditionally harvested stems

There were no significant differences between the Spring and Autumn Wrench treatments in mean leaf length (Figure 4.1, Table 4.2), although there were strongly significant differences between the sites (Table 4.3; see also Figures 4.2 (a) and 4.2 (b)).

Table 4.2: Table of mean (± s.d) leaf lengths of the two traditional hand wrench treatments, for both sites. Treatment codes: AW = Autumn Wrench, SW = Spring Wrench. Leaf length ranges are in the parentheses.

	Te Kotuku Whakaoka (MOA)	**Kaimai Ranges (KAI)**
AW	93.9 cm ± 34.9 cm (10 – 151 cm)	84.6 cm ± 30.2 cm (10 – 129 cm)
SW	93.6 cm ± 29.5 cm (12 – 130 cm)	90.4 cm ± 28.7 cm (12 – 135 cm)

Table 4.3: ANOVA table summarising results of comparisons of leaf lengths of the two traditionally hand wrenched stems (Spring (SW) and Autumn Wrench(AW)). Significant *p*-value (< 0.05) is highlighted in bold.

Source	Df	SS	MS	F	*P*
Site	1	10686	10686	11.12	**<0.0001**
Treatment	1	1903	1903	1.98	0.16
Site x Treatment	5	2545	2545	2.65	0.10
Residuals	1030	989834	961		

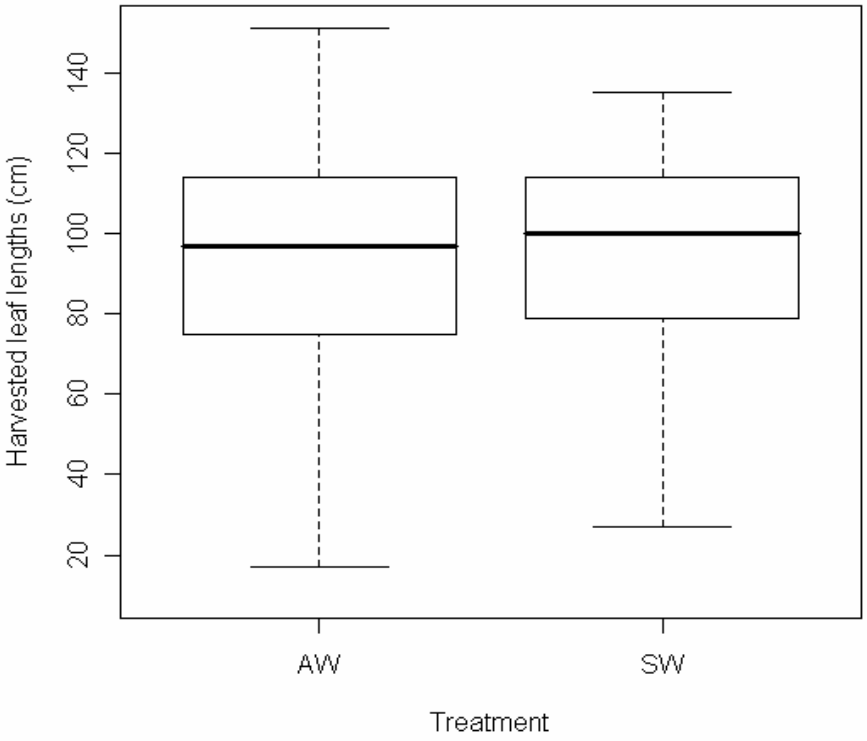


Figure 4.1: Boxplot showing the average leaf lengths (cm) of the two traditionally harvested stems across the two sites. Leaves that were measured in this dataset started from the first leaf ≥ 10cm at the stem tip. AW = Autumn Wrench, and SW = Spring Wrench.

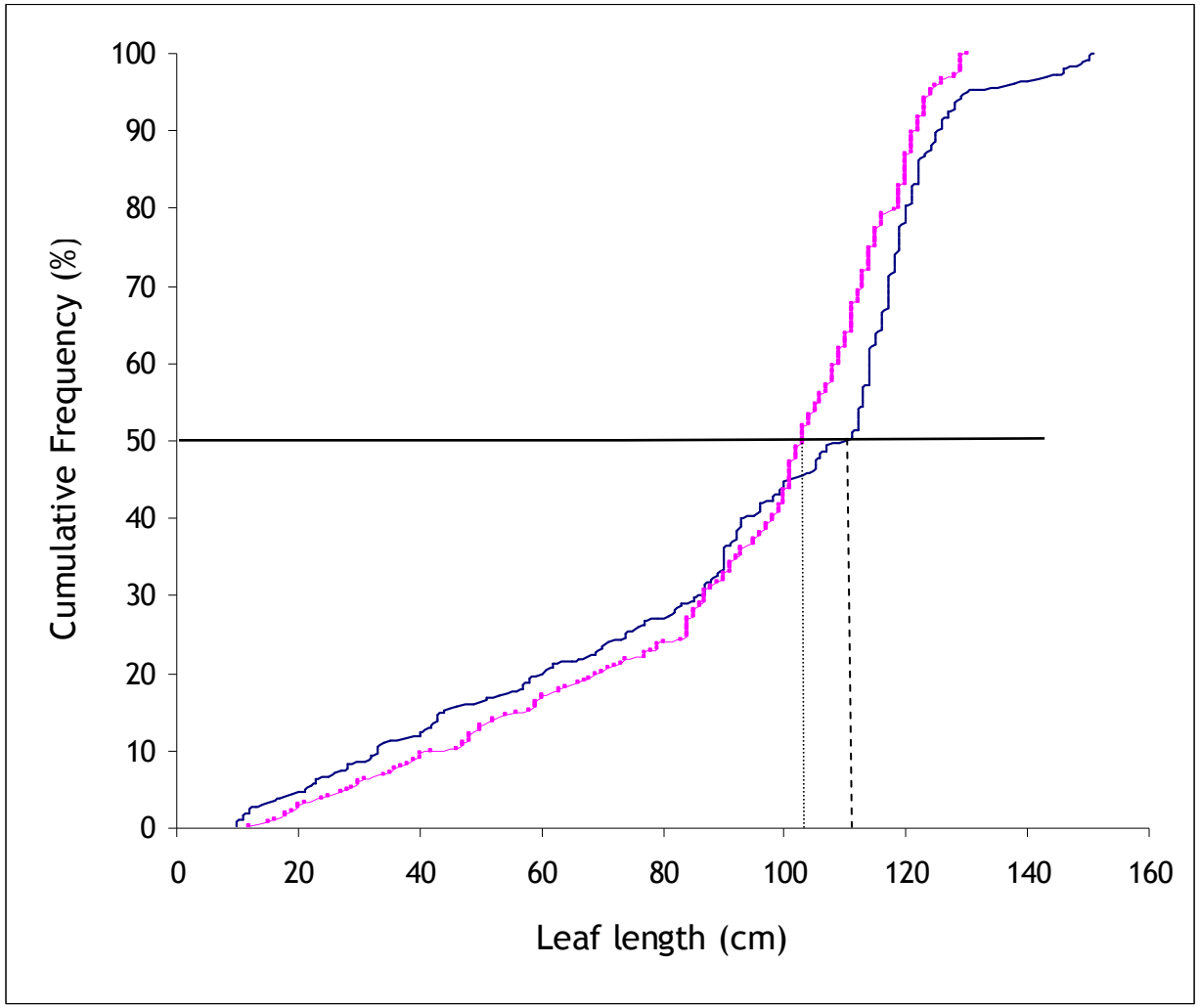


Figure 4.2 (a): Cumulative frequency graph depicting the leaf lengths of all leaves ≥ 10 cm harvested from Te Kōtuku Whakaoka (**MOA**), using the traditional hand wrench treatments (AW and SW). Autumn Wrench (AW) stems are represented by the blue line, and the pink line represents the Spring Wrench (SW) stems. The black horizontal line marks the 50th percentile. The vertical dotted line (left) indicates the approx. leaf length falling within that percentile for the SW (~ 116 cm). The vertical dashed line (right) indicates the approx. leaf length falling within that percentile for the AW (~ 102 cm).

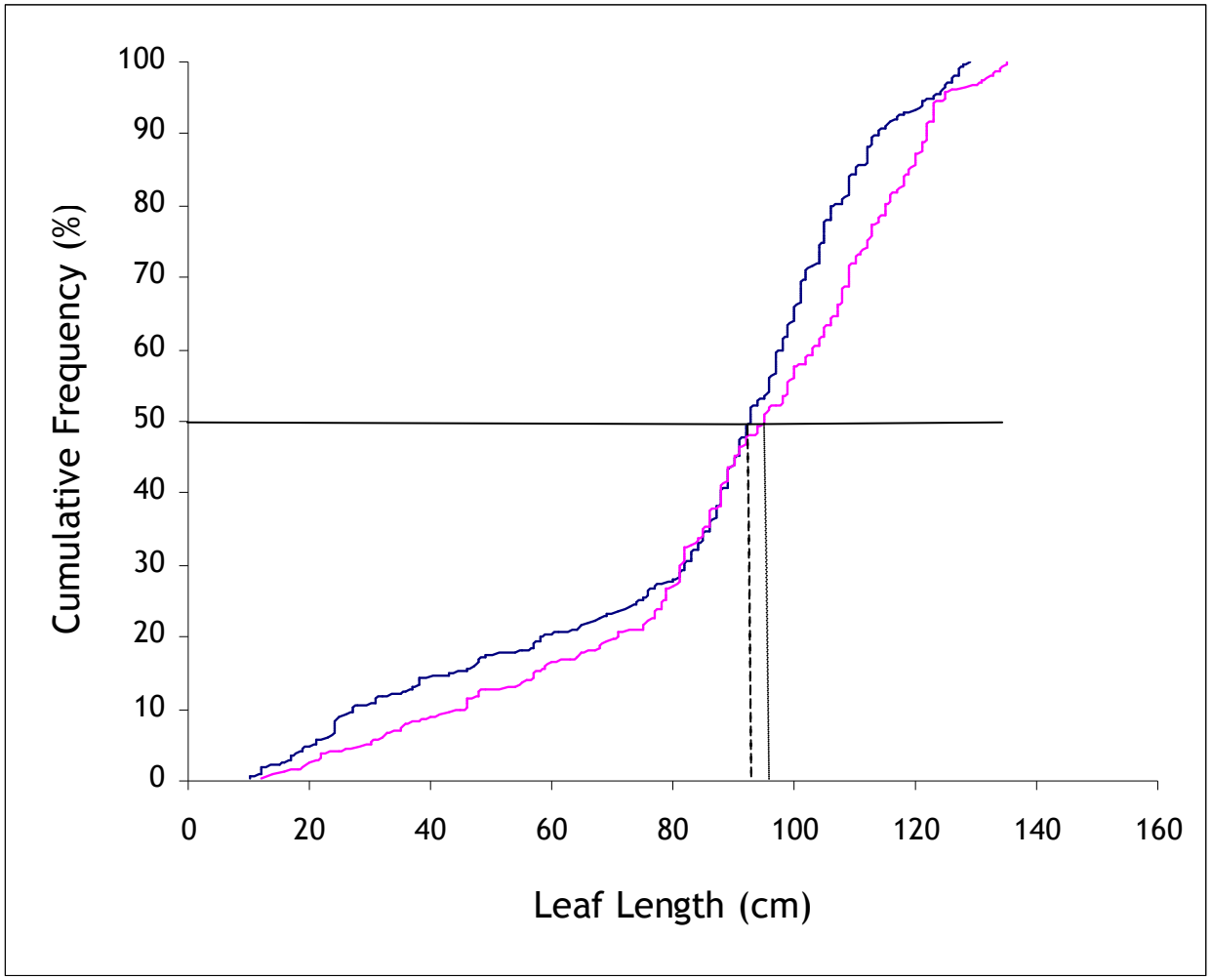


Figure 4.2 (b): Cumulative frequency graph depicting the leaf lengths of all leaves ≥ 10 cm harvested from the Kaimai Ranges (**KAI**), using the traditional hand wrench treatments (AW and SW). Autumn Wrench (AW) stems are represented by the blue line, and the pink line represents the Spring Wrench (SW) stems. The black horizontal line marks the 50th percentile. The vertical dotted line (left) indicates the approx. leaf length falling within that percentile for the SW (~ 93 cm). The vertical dashed line (right) indicates the approx. leaf length falling within that percentile for the AW (~ 96 cm).

4.4.1.1 Categorisation of leaf lengths into size classes

In addition to potential differences between the two traditional harvest treatments in average total leaf lengths, there was also a question raised as to potential differences in a particular size class (Figure 4.3); e.g. the number of long leaves (over 91 cm). Results of the ANOVA on the number of leaves $\geq$ 91 cm showed a significant site effect, but a non-significant treatment effect (Table 4.4).

Table 4.4: Summary of results of Poisson ANOVA comparing the number of leaves $\geq$ 91 cm between the Spring, and Autumn Wrench. Significant *p*-value (< 0.05) is highlighted in bold.

Source

	Df	Dev.	Res. Df	Res.Dev	F	*P*
NULL			7	241.67		
Site	1	4.86	6	236.81	4.86	**0.03**
Treatment	1	0.04	5	236.76	0.04	0.84
Site x Treatment	1	1.60	4	235.16	1.60	0.21

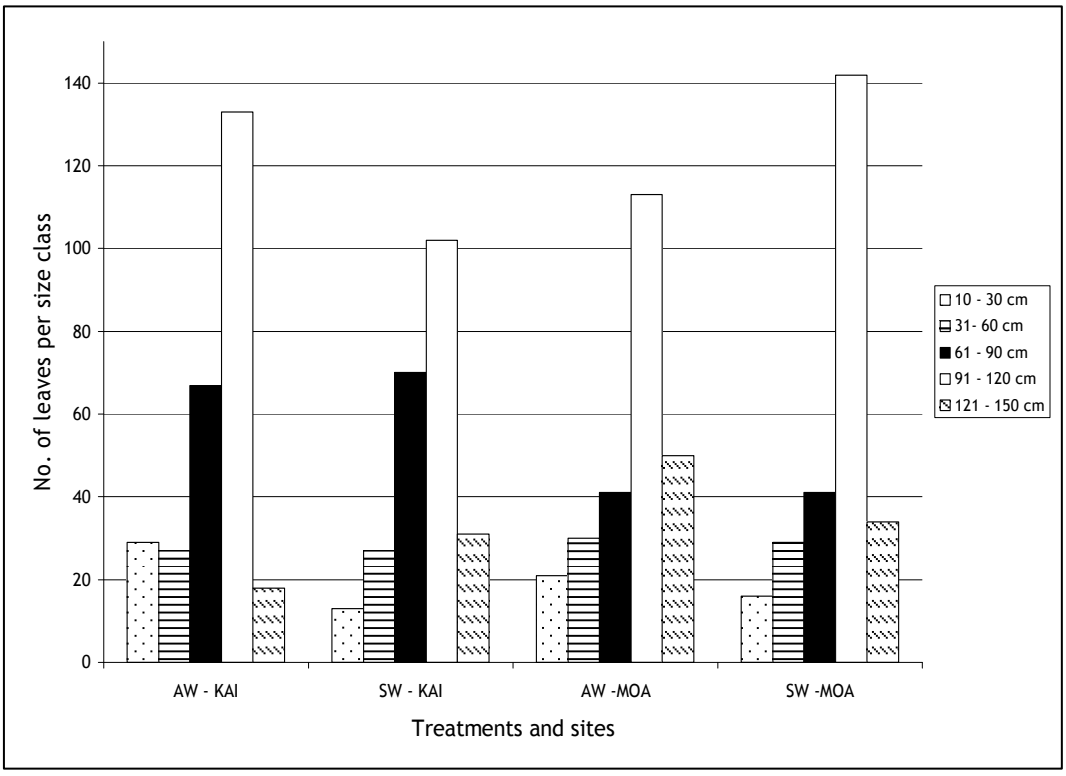


Figure 4.3: Histogram of the total number of leaves in each of the leaf length size classes, divided into treatments and sites. The statistical analysis described earlier was conducted on the last two size classes – 91 – 120 cm and 121 – 150 cm.

4.4.2 Leaf Counts - All harvest treatments

Results of a ANOVA test on the number of leaves harvested with all four treatments showed strongly significant results for site, block (within site), and treatment (Table 4.5). The number of leaves removed from stems using the Autumn Fully-cut method were almost three times the number of the traditionally hand wrenched treatments (Autumn and Spring Wrench), and total leaves in the Autumn Herbivory were over double the amount of the traditional methods (Figure 4.4).

Table 4.5: Summary of results of the Poisson ANOVA test on the total number of leaves harvested in each of the four harvest treatments (AF = Autumn Fully-cut, AH = Autumn Herbivory, AW = Autumn Wrench, SW = Spring Wrench). Significant p-values (< 0.05) are highlighted in bold.

Source	Df	Deviance	Res. Df	Res. Dev	F	*P*
NULL	74	881.22				
Site	1	5.65	73	875.56	5.65	**0.017**
Block	18	37.94	55	837.63	2.11	**0.004**
Treatment	3	797.07	52	40.56	265.69	**< 0.0001**
Site x Treatment	5	2.13	49	38.43	0.71	0.55

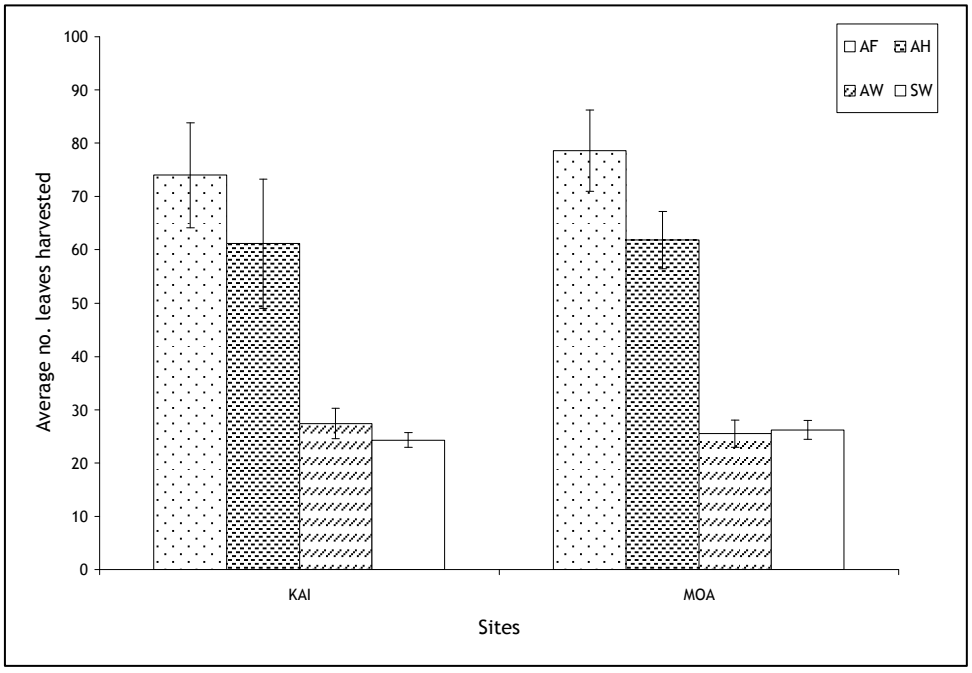


Figure 4.4: Bar graph of the total number of leaves in each of the harvest treatments for each site. The two sites are MOA = Te Kōtuku Whakaoka, and KAI = Kaimai Ranges. AF = Autumn Fully-cut (non-traditional method); AH = Autumn Herbivory; and the two traditional methods of harvest - AW = Autumn Wrench and SW = Spring Wrench.

4.4.2.1 Traditionally harvested stems

An analysis of the number of leaves harvested in the traditional hand wrenches showed a non-significant difference between the two treatments (Table 4.6; Figure 4.5).

Table 4.6: Summary of the results of Poisson ANOVA tests comparing the number of leaves removed with the traditional harvesting methods – Autumn Wrench (AW) and Spring Wrench (SW).

Source	Df	Deviance	Res. Df	Res. Dev	F	*P*
NULL			39			
Site	1	0.00	38	14.91	0.00	1.00
Block	18	9.20	20	14.91	0.05	0.96
Treatment	1	0.56	19	5.71	0.56	0.46
Site x Treatment	3	1.40	18	3.76	1.40	0.24

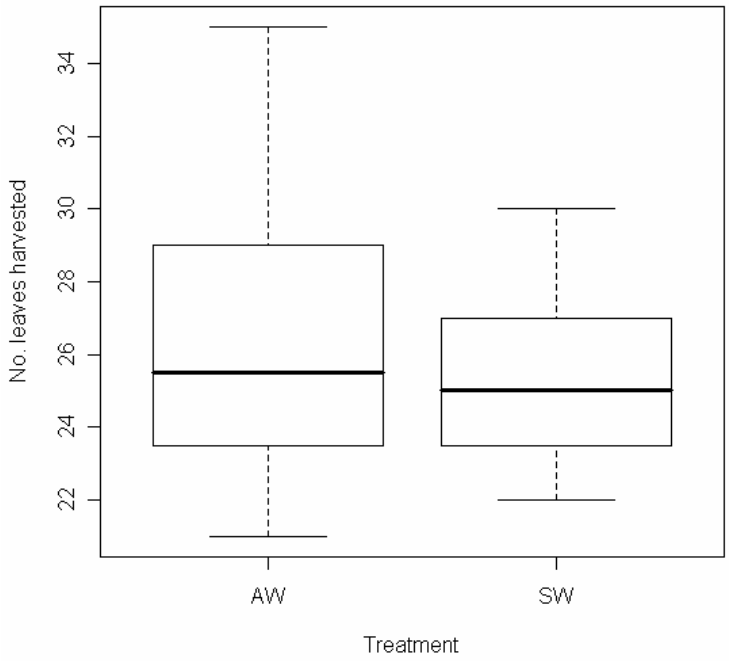


Figure 4.5: Boxplot of the total number of leaves harvested in the traditional hand wrenches from both sites. AW = Autumn Wrench, and SW = Spring Wrenched.

4.4.3 Wet and Dry weights

4.4.3.1 All treatments

As expected there was a great deal of variability between all four treatments; with strongly significant treatment effects for wet and dry weights, and change in weight (Table 4.7). Results showed that the treatments harvested in April 2006 – Autumn Fully-cut, Herbivory and Wrench – all had heavier wet and dry weights when compared with the lighter Spring Wrench stems harvested in November 2005. The dry weight of the Autumn Fully-cut treatment was approx. four-times greater than the Autumn Herbivory and Autumn Wrench, and seventeen-times more than the Spring Wrench (Figures 4.6). There was little difference in wet and dry weights, and change in weight after drying between the Autumn Herbivory and Autumn Wrench.

Table 4.7: Results of ANOVA tests comparing the weights and relative water content of the harvested material of all treatment stems. Spring Wrench (SW) stems were harvested in November 2005, Autumn harvests (Fully-cut (AF), Wrench (AW) and Herbivory (AH)) were conducted in April 2006. Significant *p*-values (< 0.05) are highlighted in bold.

(a) Wet weights (g)

Source	Df	SS	MS	F	*P*
Site	1	8427	8427	0.33	0.57
Block	18	782621	43479	1.69	0.07
Treatment	3	10624328	351443	137.68	**<0.0001**
Site x Treatment	3	51496	17165	0.67	0.58
Residuals	53	1363295	25723		

(b) Dry weights (g)

Source	Df	SS	MS	F	*P*
Site	1	92	92	0.05	0.83
Block	18	62646	3480	1.73	0.06
Treatment	3	699774	233258	115.82	**<0.0001**
Site x Treatment	3	2042	681	0.34	0.80
Residuals	53	106742	2014		

Table 4.7 contd. (c) Change in weight (g)

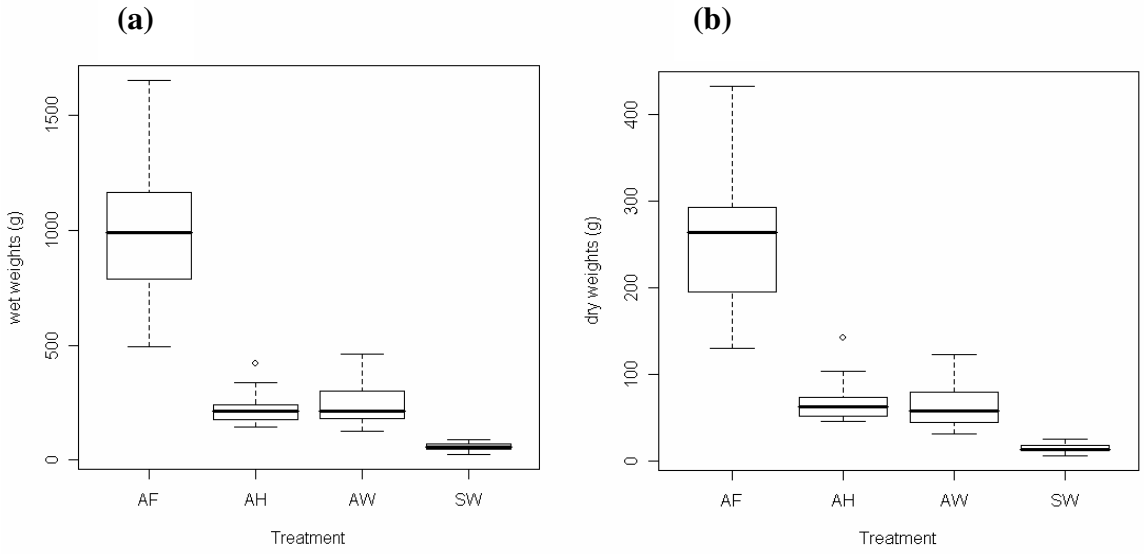
Source

	Df	SS	MS	F	*P*
Site	1	6754	6754	0.50	0.45
Block	18	410604	22811	1.67	0.08
Treatment	3	5878631	1959544	143.49	**<0.0001**
Site x Treatment	3	33478	11159	0.82	0.49
Residuals	53	723793	13656		

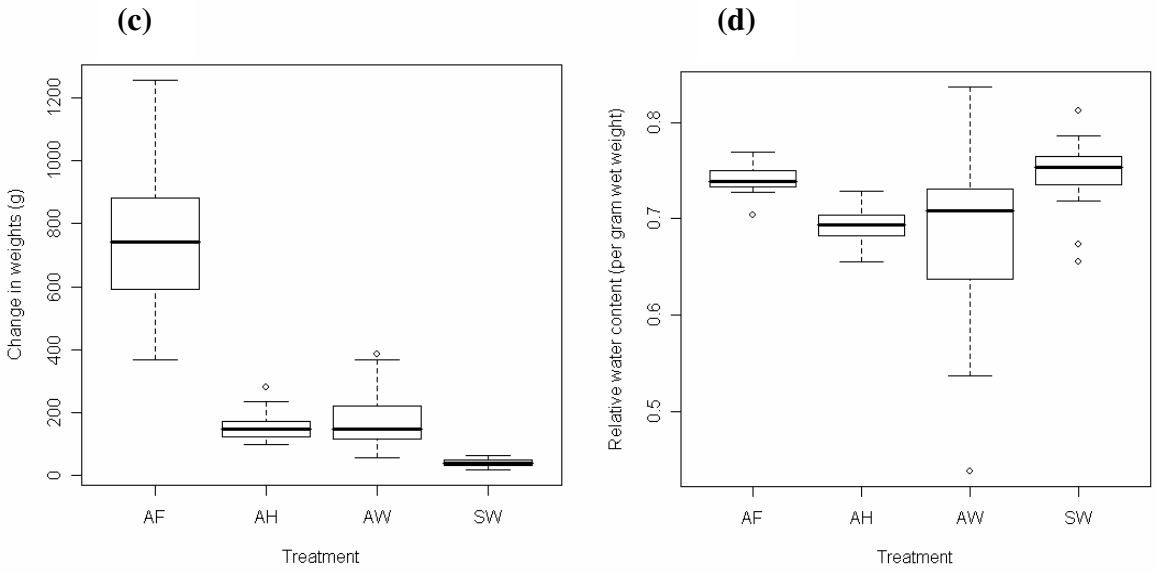
(d) Relative water content

Source

	Df	SS	MS	F	*P*
Site	1	0.0004	0.0004	0.94	0.34
Block	18	0.02	0.001	2.24	**0.01**
Treatment	3	0.04	0.01	28.29	**<0.0001**
Site x Treatment	3	0.0002	0.00005	0.11	0.95
Residuals	53	0.02	0.0005		



Figures 4.6 (a) – 4.6 (b): Boxplots of the **(a)** wet and **(b)** dry weights (g) of all treatments [note the change in scale between the two graphs] Weights include stem material and leaves for all harvested kiekie stems. AF = Autumn Fully-cut, AH = Autumn Herbivory, AW = Autumn Wrench, SW = Spring Wrench.



Figures 4.6 (c) – 4.6 (d): (c) change in weight (g) between wet and dry, and **(d)** the relative water content for all treatments. Weights include stem material and leaves for all harvested kiekie stems. AF = Autumn Fully-cut, AH = Autumn Herbivory, AW = Autumn Wrench, SW = Spring Wrench.

Comparisons of the relative water content of all harvested treatment stems was tested to see if there were any differences in the water content, between the four treatments (Table 4.7 (d)). Results of the ANOVA showed that there was a significant difference between the treatments. Water content was greater in both the Autumn Fully-cut (~ 0.74) and Spring Wrench treatments (~ 0.75), whilst the Autumn Herbivory and wrench treatments had a water content of ~ 0.69 and ~ 0.68 respectively (Figure 4.7 (d)). Despite there being no sign of a block effect in the earlier analyses, it was strongly significant in this analysis (Table 4.7 (d)).

4.4.3.2 Traditionally harvested treatments

Analyses for differences between the two traditional wrench treatments showed that there were pronounced differences in the water contents, with the pattern holding for both sites. Results of an ANOVA on weight change after drying (Table 4.8 (a)) supported the differences in weight decreases observed within the wider treatment analysis earlier. Autumn Wrench wet weights were three-times greater than the Spring Wrench. Weights after drying suggested that the Autumn Wrenched stems held eight times more weight in dry matter than the Spring Wrenches (Figure 4.7).

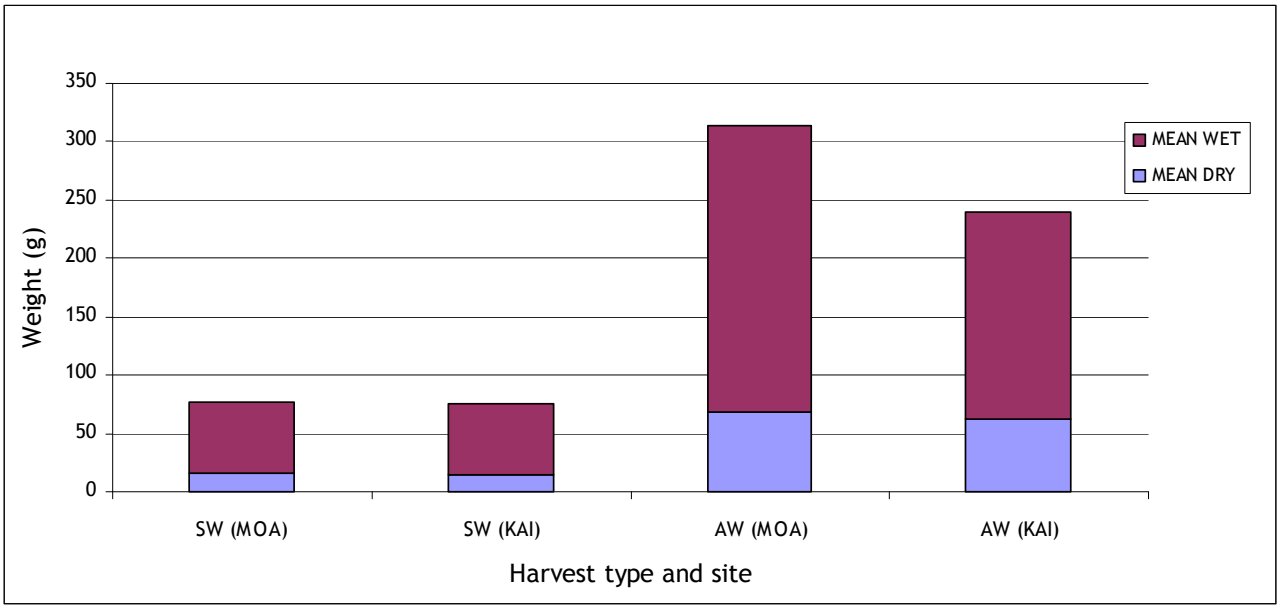


Figure 4.7: Stacked bargraphs showing differences in wet and dry weights between treatments; site labels are in parentheses. Weights include stem material and leaves for all harvested kiekie stems. KAI = Kaimai Ranges, MOA = Te Kotuku Whakaoka. Treatments: AW = Autumn Wrench, SW = Spring Wrench.

The results of an ANOVA on the relative water content of each harvested stem after drying showed a highly significant difference between the two treatments, and also produced a significant site and treatment interaction effect (Table 4.7 (b)). This interaction effect is explained by the differences observed in the two Autumn Wrench datasets (Te Kōtuku Whakaoka and Kaimai Ranges; see Figure 4.7 above). Here, stems harvested from Te Kōtuku Whakaoka had heavier average wet weights than those harvested from the Kaimai Ranges, but decreased by a greater percentage. However, this pattern did not hold for the Spring Wrench datasets.

Table 4.8: Summary of results of ANOVA tests comparing the changes in weight and relative water content of each of the traditionally hand wrench treatments. The Spring Wrench (SW) was harvested in November 2005, and the Autumn Wrench was harvested in April 2006. Significant *p*-values (< 0.05) are highlighted in bold.

(a) Change of weight after drying

Source	Df	SS	MS	F	*P*
Site	1	27	27	0.009	0.93
Block	18	133874	7437	2.44	**0.04**
Treatment	1	146231	146231	47.90	**<0.0001**
Site x Treatment	1	411	411	0.14	0.72
Residuals	17	51902	3053		

Table 4.8 contd. (b) The relative water content

Source	Df	SS	MS	F	*P*
Site	1	0.01	0.01	2.70	0.12
Block	18	0.09	0.005	1.32	0.29
Treatment	1	0.05	0.05	12.04	**0.003**
Site x Treatment	1	0.02	0.02	4.85	**0.04**
Residuals	17	0.07	0.004		

4.4.4 Side Shoots

As outlined in chapter three, the two sets of Control stems and the Autumn Herbivory treatment failed to produce any side shoots, and so were not included in any analyses. Additionally, Autumn Fully-cut side shoots were excluded due to the lack of regeneration within Te Kōtuku Whakaoka, and the death of stems in the Kaimai Ranges. This section, therefore, only applies to the side shoots harvested from the Spring and Autumn Wrench treatment stems.

For all analyses in this section, stems were excluded from the analysis if any of their side shoots had missing data or severe leaf damage (such as invertebrate herbivory) which could compromise the totals, and final results. This applied to both the total shoot leaf count per stem, and total leaf lengths per stem, and often meant that sites had uneven samples. This is highlighted in the results if applicable.

4.4.4.1 Side shoot leaf lengths per stem

The three longest leaves of each side shoot were summed and compared to get an estimate of total leaf length per treatment stem, in order to evaluate differences in regeneration. Results of the analysis were significant for treatment effect, but non-significant for all other factors. Spring Wrench (SW) side shoots were almost double the mean total leaf length of the Autumn Wrench (AW) stems (mean SW = 252.43 cm ; mean AW = 132.11 cm; see Figure 4.8)

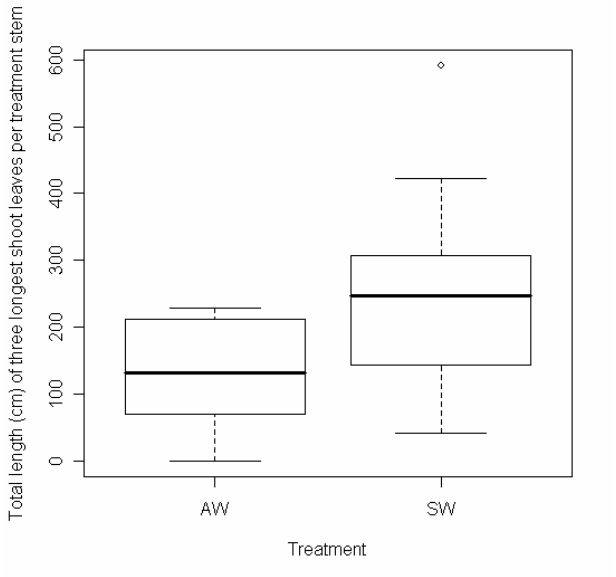


Figure 4.8: Boxplot comparing total shoot leaf length (of three longest leaves) per treatment stem.

AW = Autumn Wrench, SW = Spring Wrench.

Table 4.9: Table summarising the results of differences of summed leaf lengths (3 longest leaves)per treatment stem (Spring, SW and Autumn Wrench, AW) . Significant *p*-value (< 0.05) is highlighted in bold.

Source					
	Df	SS	MS	F	*P*
Site	1	94	94	0.006	0.94
Block	18	166082	9227	0.58	0.86
Treatment	1	138746	138746	8.74	**0.01**
Site x Treatment	1	1307	1307	0.08	0.78
Residuals	14	222369	15883		

4.4.4.2 Total number of side shoot leaves per stem

Tallies of the number of shoot leaves per stem were taken as at April 2007 for both treatments. This is different to the analysis in Chapter 3 which compared the total number of shoot leaves per stem after only one year of regeneration. As expected, differences in the total number of shoot leaves per stem were significant for all factors, with the strongest effects observed for treatment and block (Table 4.10 (a)). Results within sites were highly variable, and a divergence between sites can probably be attributed to a large difference in the site averages for the Autumn Wrench

stems (Table 4.10 (b)). Mean shoot leaf production per stem for the Spring Wrench stems was 39.95 leaves, and for the Autumn Wrench stems was 32.11 leaves (Figure 4.9).

Table 4.10 (a): Summary of results of the Poisson ANOVA test comparing the total number of shoot leaves on all side shoots per treatment stem (Spring and Autumn Wrench)Significant *p*-values (< 0.05) are highlighted in bold.

Source	Df	Dev	Res. Df	Res. Dev	F	*P*
NULL			38			
Site	1	5.72	37	351.16	5.72	**0.02**
Block	18	111.62	19	239.54	6.20	**< 0.0001**
Treatment	1	17.53	18	222.01	17.53	**< 0.0001**
Site x Treatment	1	6.52	17	215.49	6.51	**0.01**

Table 4.10 (b): Summary table of means (± s.d) of the total number of shoot leaves per treatment stem, and highlighting the variability between sites. A significant treatment effect is expected due to the differences in relative times since harvesting. 1 year for the Autumn Wrench stems and 1.5 years for the Spring Wrench stems. N = number of stems.

	Te Kotuku Whakaoka (MOA)	**Kaimai Ranges (KAI)**
AW	**36** ± 15.81 n = 10	**27.78** ± 16.38 n = 9
SW	**40** ± 13.82 n = 10	**39.4** ± 24.25 n = 10

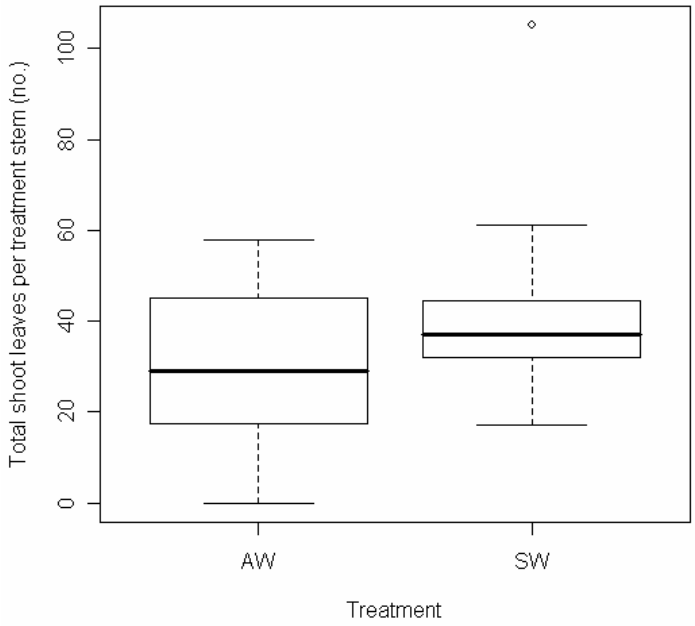


Figure 4.9: Boxplot of the total number of shoot leaves on all side shoots per treatment stem at April 2007 (t1).

4.4.4.3 Wet and dry weights

Side shoots harvested from Spring Wrenched stems had six months more growing time after harvest than the Autumn Wrenched stems, and predictably were larger (Figure 4.11). There was a strongly significant site by treatment interaction effect for the wet weights (Table 4.11 (a)), but not for the dry weights (Table 4.11 (b)).

Analyses of the respective dry weights of each group of side shoots highlighted expected differences between the two data sets. Data for the Spring Wrench side shoots showed an average of 2.5 times more dry matter than the Autumn Wrenched side shoots (Figure 4.11 (b)). Results of the change in weight after drying and the relative water content also presented strongly significant treatment effects (Table 4.11). In general, Autumn Wrench side shoots showed a much higher water content (~ 0.86) when compared to the Spring Wrench side shoots (~ 0.75) (Figure 4.11 (d)). Based on these results it appears that Autumn Wrench side shoots are holding more water per gram of dry matter than the Spring Wrenched side shoots. There were significant site and treatment interaction effects in the results of both the change in weight (Table 4.11 (c)) and the relative water content (Table 4.11).

Table 4.11: ANOVA tables summarising results of comparisons of the weights and relative water content of the side shoots produced on the Spring (SW) and Autumn Wrench (AW) treatment stems. Spring Wrench stems were harvested in November 2005 and side shoots measured were 1.5 years after harvest. The Autumn Wrench stems were harvested in April 2006 and side shoots measured were 1 year after harvest. Significant *p*-values (< 0.05) are highlighted in bold.

(a) Wet weights

Source

	Df	SS	MS	F	*P*
Site	1	34.39	34.39	1.00	0.33
Block	18	844.39	46.91	1.37	0.28
Treatment	1	1886.67	1886.67	54.94	**<0.0001**
Site x Treatment	1	325.40	325.40	9.48	**0.008**
Residuals	14	480.82	34.34		

(b Dry weights

Source

	Df	SS	MS	F	*P*
Site	1	0.13	0.13	0.07	0.80
Block	18	44.05	2.45	1.34	0.30
Treatment	1	138.76	138.76	76.05	< **0.0001**
Site x Treatment	1	0.26	0.26	0.14	0.71
Residuals	14	25.55	1.83		

(c) Change in weight after drying

Source

	Df	SS	MS	F	*P*
Site	1	38.70	38.70	1.62	0.22
Block	18	532.72	29.60	1.24	0.35
Treatment	1	1002.12	1002.12	41.87	**<0.0001**
Site x Treatment	1	307.24	307.24	12.84	**0.003**
Residuals	14	355.08	23.93		

(d) Relative water content

Source

	Df	SS	MS	F	*P*
Site	1	0.014	0.014	3.92	0.07
Block	18	0.12	0.007	1.30	0.31
Treatment	1	0.09	0.09	26.73	**0.0001**
Site x Treatment	1	0.02	0.02	6.59	**0.02**
Residuals	14	0.05	0.003		

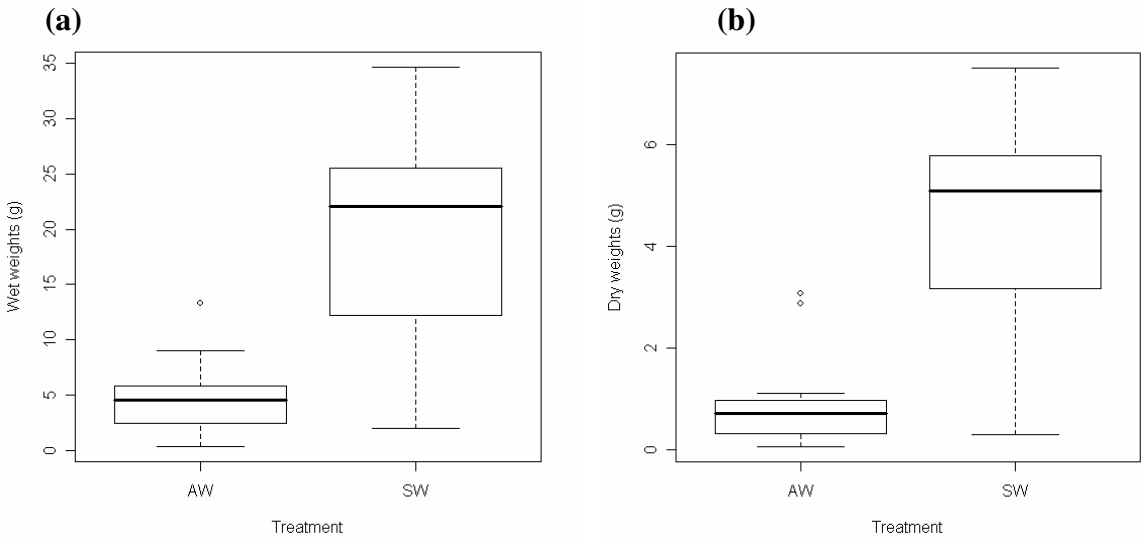
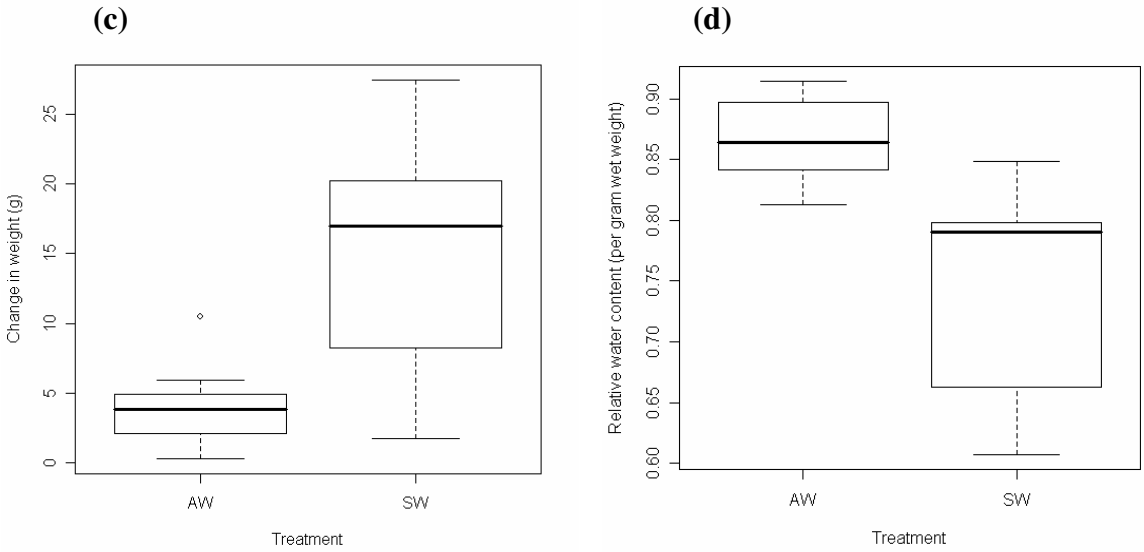


Figure 4.11: Boxplots of the **(a)** wet and **(b)** dry weights (g) of the side shoots for both treatments. **(c)** change in weight (g) between wet and dry, and **(d)** the relative water content for the side shoots of both treatments. AW = Autumn Wrench (n =17); and SW = Spring Wrench (n =19); Results of a treatment effect were significant for all datasets.



4.5 DISCUSSION

4.5.1 Costs of harvest to the stems

No matter the type of treatment, material harvested from the sites in autumn (April 2006) carried a substantially greater amount of both wet and dry weight when compared to material harvested in spring (November 2005). Results of the wet and dry weights of the Autumn Wrench and Spring Wrenched stems showed that the Autumn Wrench stems were heavier in wet weight by three-times, and by eight-times in dry weight. The differences in dry weights may be explained by the results of the relative water content which showed that Spring Wrench stems had higher average water content (0.75) than the Autumn Wrench stems (0. 68).

Comparisons between the harvest treatments in autumn also showed significant results. The Autumn Fully-cut treatment was three-times heavier in wet weight, and four-times heavier in dry weight than the Autumn Wrench, although there was little difference in both wet and dry weights between the Autumn Wrench and the Autumn Herbivory. The larger weights of the Autumn Fully-cut are likely explained by the three-fold increase in total leaf number harvested, when compared with the Autumn (and Spring) Wrenched stems. However, the non-significant results for number of leaves (p = 0.46), and leaf lengths (p =0.16) between the two traditional hand wrench treatments (Autumn vs. Spring), do not fit this pattern. With such large differences apparent between the Autumn and Spring Wrench stems, the question remains then, whether the loss of these resources from the stems is likely to inhibit the ability of the autumn treatment stems to recover at a similar rate to the Spring Wrenched stems?

Plant recovery after harvest can be determined by measurable indicators to gauge how well a plant has coped with defoliation. For this study, recovery was measured by monitoring the reproduction of new biomass in the form of side shoots (Figure 4.12 above), and then comparing this regeneration to the amount of biomass removed. For the experiment, the non-traditional method resulted in 100 % foliage removal. The absence of side shoot regeneration on more than 50% of the Autumn Fully-cut stems, does suggest that plant recovery had decreased substantially due to the percentage of biomass removed. Additionally, the Autumn Herbivory treatment removed ~ 50 % of the leafy biomass, and once again, there was a failure to vegetatively regenerate. However, this is probably because there was no damage inflicted on the stem, and

consequently, the plant was not provided with the usual cues to regenerate and/or repair. Whether this means that it had a lowered recovery is something that will be discussed in more detail in Chapter 5.

Figure 4.12: Two side shoots growing from below the break caused by traditional hand wrenching on a Spring Wrench stem in Te Kōtuku Whakaoka. Photo taken in November 2006, one year after the initial harvest in November 2005.

In theory, the lower biomass (dry weight) of the Spring Wrench stems would suggest that these stems would have a faster / better recovery than the heavier Autumn Wrench. Results indicated that the regenerating biomass (side shoots) of the Autumn Wrench had replaced approx. 2.7 % (1.76 g) of the original biomass lost through harvest (65.58 g) (see Table 4.12). To recover this biomass the side shoots would have to put on an additional 25 g of dry weight per side shoot. Comparatively, the Spring Wrench side shoots had replaced 70 % (10.67 g) of the lost biomass, and would only have to recover a further 1.9 g in dry weight per side shoot to replace the amount that was lost through harvest (15.23 g). It is difficult to say for certain however, whether this means that the Spring Wrench stems have recovered better due to differences in the developmental stages of the respective side shoots when they were removed from the field in April 2007. Autumn Wrench stems had only been harvested 1 year before, and Spring Wrench

stems had been harvested 1.5 years which meant that side shoots on the stems of the latter treatment had an extra six months of development.

Table 4.12: Summary table comparing the biomass removed, and the biomass regenerated for each traditional hand wrench treatment stem. The final column presents an estimate of the weight per side shoot to recover the lost biomass.

Treatment	Dry weight harvested	No. shoots produced	Dry weight regenerated (= dry weights lgest shoots x no.shoots)	Development stage of side shoots	Required to recover loss (= biomass removed / no. p.stem shoots)
SW	15.23 g	2.35	10.67 g	1.5 years	1.9 g
AW	65.58 g	2.55	1.76 g	1 year	25.0 g

Treatments: SW = Spring Wrench, AW = Autumn Wrench.

In Chapter 3, comparisons of total shoot leaf number per stem after one year showed that the Autumn Wrench and Spring Wrench stems were developing at a similar rate but with some variation. The Spring Wrench stems produced an average of 26.9 new shoot leaves per stem, whilst the Autumn Wrench stems produced an average of 32.11 new shoot leaves per stem. The summed leaf lengths of the three longest leaves on all side shoots per Autumn Wrench stem gave a total of 132.1 cm. Results in this chapter showed that the number of new shoot leaves produced per Spring Wrench treatment stem in the six months following that time were almost half of the original value again to get an average total of 39.95 leaves. Unfortunately there are no data at the 1.5 years after harvest stage for the Autumn Wrench stems. The summed leaf lengths of the three longest leaves on all side shoots per Spring Wrench stem gave a total of 252.4 cm. At this stage the total number of side shoots leaves produced on both sets of treatment stems has already exceeded the average amount of leaves that were removed through the initial harvest (AW = 26. 45; SW = 25.25).

The amount of biomass removed under a non-traditional harvest regime does appear to be a reliable indicator that recovery will be poor, yet it is not as reliable when comparing the two traditional hand wrenching treatments. Consequently this part of the study does not support the hypothesis. Rather, it appears that plant recovery after a traditional hand wrench is a product of

both the amount of biomass removed and other factors which vary seasonally. Despite the differences in biomass removed, the number of new side shoots produced was relatively the same (see chapter three). However, based on the limited information available regarding total shoot leaf number and the summed leaf lengths of all side shoots per Autumn Wrench stem at the same period as the Spring Wrench (1.5. years after harvest), it is difficult to draw any concrete conclusions as to whether there are actually any real differences in recovery between the two traditional treatments.

4.5.2 Benefits for weavers

For many weavers, the effort to harvest kiekie is increased by the decrease in accessibility to patches, particularly in the North Island. In light of the travelling distances, and the time spent in processing leaves for weaving, it was the intention of this chapter to evaluate whether effort and efficiency were improved by harvesting in one season as opposed to the other. Results showed that there were few differences found in the leaf number and leaf length harvested in the Autumn and Spring Wrench treatments. Although there was variation between the sites, overall the treatment effects on the average leaf lengths, and the number of leaves harvested were non-significant, as were the analyses of size classes and leaves over 91 cm. Therefore, efficiency and effort are not enhanced in either harvest season.

4.6 SUMMARY

Within tikanga, the traditional harvest is dictated as the most supportive to regeneration, and weavers speak of taking "*only what the plant gives you*" (i.e. the natural point of breakage) (Ranui Ngarimu, pers. comm.).

This part of the research examined the costs of harvest to kiekie and further supports traditional harvest in several ways. Firstly, there is now data to support that the snapping of the apex under the traditional harvest regime causes a positive growth response in kiekie, increasing its recovery, and replenishing the resource better than the Autumn Fully-cut. In terms of benefits to weavers though, there are no differences in leaf number or leaf length harvested between the seasonal harvests. Secondly, despite the differences in the weights of the traditional harvest treatments,

there was an indication that Autumn Wrench stems has the potential to recover as well as the Spring Wrench stems based on data after one year. To accurately compare recovery at the 1.5 year after harvest stage, there will need to be further measurements taken of Autumn Wrench side shoots to assess if this pattern holds. Thirdly, results of the non-traditional harvest and herbivory treatments supported the hypothesis with results showing that the removal of > 50 % of the biomass had some effect on decreasing plant fitness, and that 100 % foliage removal definitely retarded recovery.

CHAPTER 5 - Discussion

5.1 Failure of non-traditionally harvested stems

Previous to this research there was little in the way of quantitative data to support the observations made by weavers and kaitiaki that non-traditional methods had negative impacts on kiekie regeneration. The concerns raised by them included poorer recovery of the patch following harvest using methods which usually involved the removal of the entire leaf crowns of the affected stems. Although international literature on climbing plants implied that removal of the total aboveground biomass could have profound effects on the recovery of the stem (Raghu, *et al*., 2006), the knowledge was limited with regard to kiekie.

In the research of Raghu *et al.* (2006) into the control of an invasive climber, the cat's claw creeper (*Macfadyena unguis-cati*), it was found that the greater the percentage of foliage removed, the poorer the recovery of the plant. A gradual increase in the percentage of foliage removed in their simulations showed that the most effective means of lowering its fitness and enhancing management was to remove more than 50 %. The hypotheses outlined in chapter three and four argued that non-traditional methods of harvest would remove a greater percentage of the stem tip biomass (100 %) than any of the other treatments. Therefore, the recovery of the plant would be negatively impacted as a result of the lost carbon reserves that may have been held in the leaf biomass. Compromised recovery could then be measured by poor regeneration; i.e. no or lowered production of side shoots when compared with other treatments. The resultant analyses of both chapter three and four supported these hypotheses.

In chapter three it was shown that Autumn Fully-cut (AF) stems had a poorer recovery rate than all other treatments. Twenty five percent of the stems harvested using this method died, and more than 50 % of those stems remaining failed to regenerate with new side shoots. Of the 20 % that did regenerate, they had an average of 1.73 side shoots per stem, although this was highly skewed by one stem producing 24 new side shoots. When the outlier was removed the average dropped to 0.14 side shoots per stem, highlighting the poor recovery overall. These results were supported by the analyses into the amount of biomass removed in the *ex situ* analyses of chapter four. Autumn Fully-cut stems had the greatest wet and dry weights, and the greatest number of leaves removed.

Consequently, the costs of harvest to the non-traditionally harvested stems were much higher than any of the other treatments.

If the non-traditional practice tested in this research is continued, then kiekie stocks will be severely affected. Despite some stems producing side shoots, overall, stems are not as replenished as they might be with other techniques. Weavers argue that harvested stems can recover within four years if the traditional method is used. Based on my findings it is likely that affected stems would take a longer time to recover the lost resources if using the Autumn Fully-cut; although the exact timing is unknown. Furthermore, the results observed in this study could be exacerbated if more than one stem within the patch was harvested in this manner.

5.2 The impacts of goats on kiekie patches

The hypothesis outlined in this research argued that goat browse would have a negative impact on the recovery of the plant due to the type of damage inflicted (removal of 50 % of the total leaf area), and the consequential impacts this may have photosynthetic production and carbon uptake, therefore, slowing new leaf production. Analyses comparing the Autumn Herbivory (AH) treatment with both sets of controls showed a non-significant result for the comparison of total leaves produced over the 1.5 years of the research (p = 0.06). However, there was a strongly significant result for the year immediately following harvest.

Before harvest (between November 2005 and April 2006) the Autumn Herbivory stems were the strongest producers of new leaves. This changed between April 2006 and April 2007, with the Autumn Herbivory stems having a lower new leaf production on average than the two sets of controls (Controls-Control patch, CC; and Controls-Harvested patch, CH). Whether the reductions seen were because carbon uptake was slowed due to a reduction in the total leaf area (and hence, lowering photosynthetic production) is not completely understood. There were no measurements taken of carbon uptake and photosynthetic production before and following harvest. Consequently, there can be no concrete conclusions drawn as to whether the observations made are primarily because of a failure in these systems.

In chapter four, the hypothesis that goat browse would have a negative effect on recovery was extended to consider whether the amount removed would affect recovery of the plant. A larger

amount of biomass in terms of leaf number, and total leaf area (~ 50 %) was removed in the Autumn Herbivory treatments when compared with the two other traditional hand wrenching treatments. The wet and dry weights of the material were also heavier than the Spring Wrench (SW) stems. Yet these weights were comparable with the wet and dry weights of the Autumn Wrench (AW) treatment stems. The latter had a better recovery (in terms of new side shoots produced) than the Autumn Herbivory stems which raise some doubt regarding the above hypothesis. There was an assumption made that recovery could be measured in terms of regenerating biomass (i.e. new side shoots), though the Autumn Herbivory stems did not produce new side shoots. At the conclusion of the study, I discovered that the measurement of side shoots produced may not have been an appropriate method for measuring recovery on the herbivory stems because the stems did not have the same cues to encourage regeneration as would have occurred if the stem had been damaged. This would explain why no new side shoots were produced after harvest of those stems.

Generally, the results outlining the lack of regeneration following leaf damage coupled with the slowed new leaf production suggests that kiekie have low resistance and resilience to herbivory, the latter of which is further compounded by their naturally slow growth. Resistance is defined as any plant trait that reduces the preference or performance of herbivores (Strauss & Agrawal, 1999). Resilience usually refers to the amount of time it can take for a plant to recover from damage (Bee, *et al*., 2007). As evidenced by the type of damage that be inflicted on kiekie by goats for example (i.e., complete removal of leaf material), there is little to suggest that there are mechanisms to deter browse, such as chemical compounds; although it does deserve further investigation.

Essentially, the absence of mammalian herbivores within the New Zealand archipelago until European colonisation (Pimm, 1997) means that kiekie have not had the same opportunities to adapt to these and other exotic mammalian herbivores as plants that co-evolved with these animals would have. There is the potential for kiekie to recover from herbivory provided the animals are eradicated; a sentiment shared by Jennie Bee and her colleagues (2007) in their research into the effects of deer browse on the resilience of native New Zealand saplings. In light of the information regarding kiekie responses to leaf damage, it is important that further inroads be made into strengthening the current management of mammalian herbivores within the

conservation estate. This is particularly important when considering the heavy dependence of weavers upon kiekie resources there.

5.3 Is tikanga right? – Traditional hand wrenching methods

Population densities of harvested plants are often highly dependant on the decisions made by harvesters at both the population and landscape level (Endress, *et al*., 2004; Ticktin, 2005); and it has been suggested that sustainable harvest of flora is achievable, although the proof of such is often limited by the lack of quantitative data (Anderson & Putz, 2002). In terms of kiekie harvest, the arguments of weavers have been that traditional methods of harvest encouraged vigorous regeneration, and thus supported sustainable utilisation of the resource. In the early work of the DSIR, there were indications that traditional methods of kiekie harvest could actually replenish, rather than diminish harvested populations (Anon, 1988), however this study ended prematurely before concrete conclusions could be drawn.

To test the hypothesis first proposed by DSIR scientists that traditional harvest replenishes the resource I first needed to assess the overall effect that harvest may have on the non-harvested stems within the harvested patch. Comparisons of the Control stems in the Control patch (CC) and the Control stems in the Harvest patch (CH) gave non-significant results for treatment effects on new leaf production, and average leaf length over the 1.5 years of the research; despite two harvesting regimes (spring and autumn) occurring over that period. Overall, these results imply that there were no patch-level effects observed, although there is a limitation. As discussed in chapter three, I made an assumption that all stems within the 'harvest patch' were connected. Despite their close proximity to one another, it is possible that this may not have always been the case. Due to the propagative nature of kiekie, stems can become separated from the parent stem, and root as individual genets (Gerwing, 2004; Schnitzer & Bongers, 2002). Consequently, the results in this part of the study should be regarded with this in mind.

As outlined in sections 5.1 and 5.2 another of the hypotheses tested in this research was whether the recovery rate of the harvested stem is symptomatic of the amount of biomass removed. Earlier results for the Autumn Fully-cut (AF) definitely support the theory that the removal of greater amounts of biomass will dictate poorer recovery. Overall, the outcome of the study proved that tikanga regarding traditional methods vs. non-traditional was correct with

traditionally hand wrenched stems showing greater recovery than the non-traditional Autumn Fully-cut stems (refer back to section 5.1).

However, the results for the traditionally harvested stems did not sustain the idea that a greater biomass removed will equate to poorer regeneration, and instead showed the opposite indicating that the season when harvest occurs may be important for regeneration. Autumn Wrench (AW) stems had heavier wet and dry weights than the Spring Wrench (SW) stems implying that there may have been more of the stem's stores removed with the biomass in autumn; and yet recovery was comparable for the number of side shoots produced by both treatment stems. These differences could not be explained by leaf number or leaf lengths as the results for these were also non-significant for differences.

Results of the total leaves of all side shoots per treatment stem one year after harvest also indicated that the Autumn Wrench stems appear to have a greater competitive advantage in terms of the total new leaf area (AW = 32.1 and SW = 26.9 total shoot leaves per stem) despite the higher apparent loss to the stem. There are questions though as to whether this growth spurt can be maintained by the Autumn Wrench side shoots. Because these side shoots were harvested before they had reached the same developmental stage as the Spring Wrench side shoots (1.5 years after harvest), it is difficult to make any further inferences about differences between the treatments.

It can be concluded that harvested kiekie patches do recover from traditional harvest, although to what degree these results may or may not change it is not known due to the short duration of this research. It is possible that the significant differences in recovery for all of the treatment stems may become more pronounced as the new side shoots mature, and this is worth investigating in the future[3].

Bearing the short time frame in mind, the arguments of weavers that traditional harvest can replenish the resource are supported in this study as shown by the new leaf area developed on the regenerating side shoots. One-year after harvest, the Autumn Wrench stems had produced 32.11 total shoot leaves on all side shoots per treatment stem. One and a half years after harvest, the Spring Wrench stems had produced 39.95 total shoot leaves on all side shoots per treatment stem.

[3] Note that annual monitoring is still occuring at each of the sites.

It is generally accepted that climbing plants allocate a significant amount of carbon to their leaves for storage (Givnish & Vermeij, 1976; Putz, 1983), a characteristic that can begin around the onset of leaf ontogeny (Castellanos, 1991). Past studies of the common bean vine (cited ibid) showed that peak sink activity (exporting and importing of photosynthate for growth and construction) is attained when new shoot leaves are approx. 10 % of their final leaf length (size). This process continues until leaves are at ~ 45 % of their final size, when leaves then act exclusively as a source of photosynthate.

This 'pay back' has been interpreted as the process by which the plant recovers the investment it made into the development of a new shoot (Castellanos, 1991). Net photosynthesis actually increases to a distinct peak around the period when new shoot leaves are at 10 % of their final size and continues to near full leaf expansion, when it then declines as the leaf approaches senescence (Castellanos, 1991). Although the particular study referred to here applies to natural recruitment processes, the theory should also apply to the development of new side shoot leaves in response to traditional harvest.

Results of the leaf area of the developing side shoots showed some promising results with regard to recovery. For the Autumn Wrench stems, the average length for each of the longest three leaves of each side shoot per stem was 17.27 cm. This equates to ~ 19% of the average leaf length of a mature leaf which was harvested as part of the hand wrenching treatment in April 2006 (mature leaf length = 89 cm). For the Spring Wrench stems, the average length for each of the three longest leaves of each side shoot per treatment stem of 35.80 cm. This equates to ~ 38 % of the average leaf length of a mature leaf which was harvested as part of the hand wrenching treatment in November 2005 (mature leaf length = 92 cm). According to the results of the common bean vine outlined above, this would then indicate that the side shoots of both of the treatment stems have already begun 'paying back' for their development, and inadvertently for the cost of human harvest. If the model of photosynthesis in bean shoot leaves also fits kiekie, this means that the Autumn Wrench side shoots are already sequestering and supplying photosynthate to the greater leaf area (> 10 % final size), and that the Spring Wrench side shoots are almost at the point where they are exclusively a source of photosynthate.

The (potentially) positive results regarding regeneration of the stems' total leaf area likely explain the findings of the final analyses for biomass loss (dry weights) and recovery. Dry weights of the

harvested Autumn Wrench stems were 65.58 g, compared to 15.23 g for the Spring Wrench stems. Results of regenerated biomass at one year after harvest (Autumn Wrench stems) showed a recovery of 2.7 % of the lost biomass. Comparatively, one and half years after harvest, the Spring Wrench stems had recovered 70 %. The lower recovery makes sense for the Autumn Wrench stems. Spring wrench side shoots have had six months more to sequester photosynthate for growth and construction, hence the higher dry weights. It is likely that biomass measurements of Autumn Wrench side shoots at the same stage would present similar findings, although claims of greater recovery than the Spring Wrench stems would be conjecture despite the better recovery at the one year after harvest stage (see earlier). Due to this, there can be no solid conclusions drawn about whether one season is better than the other, and deserves further investigation. Overall, the combined findings for side shoot development show that the recovery of the hand wrenched stems are not negatively impacted by the traditional harvest regime (Table 5.1).

Table 5.1: Summary of results of the analyses on the traditional hand wrench treatments and the conclusions. There was little difference between the two treatments for most of analyses. However, there were more shoot leaves on all side shoots per treatment stem on the Autumn Wrench (AW) stems, when compared with the Spring Wrench (SW). Spring Wrench stems were harvested in November 2005, and Autumn Wrench stems were harvested in April 2006.

Measurement	**Result and Conclusion**
• Stem diameter (cross-sectional area)	Non-significant difference; AW = SW
• Stem death	Both nil, AW = SW
• No. side shoots produced	Non-significant difference; AW = SW
• Total no. shoot leaves p. treatment Stem (1 year after harvest)	AW > SW

5.4 CONCLUSIONS

This research is the first comprehensive investigation into harvest of kiekie, although it is not the first to support indigenous knowledge regarding plant harvest (see Ghmire, *et al.*, 2005). This study has not only been successful in terms of showing how science can be used to support indigenous knowledge, but it has provided the quantitative data to validate the concerns of Te Roopu Raranga Whatu o Aotearoa, kaitiaki and indigenous resource managers.

Non-traditional methods such as the Autumn Fully cut are detrimental to the sustainability of the resource, and contradict the responsibilities of humans (as teina) to care for and protect natural whakapapa. An additional outcome of this study was the surprisingly large effects of simulated goat herbivory observed on kiekie stems. Because ungulates are found in many areas of the conservation estate, where many kiekie are harvested from, it is important to consider the impact they have on cultural resources, and perhaps work with tangata whenua to devise strategies that can better protect populations.

Results from this research support the arguments that traditional harvest methods are sustainable, and furthermore, that population density can be improved by the method in terms of the new biomass regenerated. However, the short duration of this research means that for many of the stems, the full effects of each treatment could not be fully expressed. This may explain some of the site differences observed in leaf lengths, stem area, and side shoot production for example, highlighting that a longer term study is required if the full effects of harvest on the stem and patch are to be completely understood. With this caveat in mind, there are strong indications in the results that the traditional hand-wrenching technique has the least impact to the plant when compared to the Autumn Fully-cut and Herbivory treatments. The removal of the top third of the leaf head (apex) encourages (often) vigorous side shoot development, enhancing the leaf area of the stem. When comparing the two traditional methods, it was found that there may be a timing factor in terms of plant regeneration, with results indicating that the Autumn Wrench treatment had a faster recovery and would appear to be the best harvesting method.

CHAPTER 6 - References

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